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THERMAL RADIANCE SPECTRA 8 TO 16 MICRONS. NO. 1. WHITE SANDS AND THE MALPAIS (LAVA) C-47 AIRCRAFT

... A. HOVIS, JR.

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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WHITE SANDS AND THE MALPAIS (LAVA) C-47 AIRCRAFT

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INTRODUCTION

A filter wedge spectrometer was used over desert terrain near El Paso, Texas to record the spectral signature of earth spectral radiant emittance from 8 to 16 microns. The spectrometer is of the type described by Hovis, Kley and Strange[1] equipped with a temperature controlled thermistor bolometer detector and having a resolving power $\lambda/\Delta\lambda = 50$ from 8 to 13.7 microns and $\lambda/\Delta\lambda = 100$ from 13.7 to 16 microns. A small break in the spectra denotes the change from the lower to higher resolving power segments. A complete scan was accomplished every 30 seconds.

The spectrometer was mounted in the bottom of a C-47 type aircraft, NASA 636, from the Lewis Research Center. The aircraft was piloted by William Swann and Byron Batthauer and crewed by George Ford, all of the Lewis Research Center.

WHITE SANDS

The White Sands area consists of rolling dunes of gypsum sand bordered by Alkali Flat to the West. The gypsum (hydrated calcium sulfate) is remarkably pure, for a naturally occurring surface material, and exhibits a strong reststrahlen or residual ray effect near 9 microns as shown in Figure 1. This reststrahlen that appears as a strong maximum in reflectance measurements would result in a minimum of emissivity and hence should result in an equivalent black body temperature lower at the wavelength of the reststraheln than at nearby wavelengths where the gypsum is more nearly black.

In the 9 micron spectral region thermal energy completely predominates over reflected solar energy from earth so the spectrometer sees a combination of radiant emittance from the surface and from the intervening atmosphere and radiant emittance from the atmosphere reflected off the surface. In a reasonably clear atmospheric window the last two will contribute little but the long wavelength wing of the 6.3 micron water vapor window intrudes into the 9 micron region and, to some extent, interferes with surface observations.

Another effect that interferes with the observation of the effect of reststrahlen is the lack of flatness of the surface observed. Most laboratory measurements, including the one shown in Figure 1, are made on surfaces that are reasonably flat while in nature, such as the case of White Sands, the surface is not so

conveniently flat. The rolling dune shape of the gypsum sand tends to increase emissivity at all wavelengths much as one produces a laboratory black body by blackening the walls of a hollow cone. For the sake of calculation a simple, conical model was assumed for the dunes with an angle between faces of θ_c as shown in Figure 2. The emissivity, as a function of wavelength, was then calculated for several angles and compared with the measured result for the flat case. It can be seen that reststrahlen effect would be expected to diminish in intensity as the dune faces became steeper.

To test all of these concepts flights were made on October 15, 1967 over White Sands along a flight path as shown in Figure 3. Table 1 summarizes the pertinent data for each flight listing run number, time at start and end of each run, altitude (MSL), outside air temperature and direction of the run. Figure 4 summarizes the results showing three spectra at various altitudes compared with the calculated result for the flat case previously shown in Figure 2. The temperature for the calculated effect was assumed to be 292°K corresponding to the range of equivalent black body temperatures observed from 10 to 12 microns. The reststrahlen effect can be clearly seen in the plot of equivalent black body temperature vs wavelength and is not too severely diminished with increasing altitude. The minima of the laboratory and field measurements do not coincide exactly, probably due to mild interference by water vapor at the shorter wavelength edge. Nevertheless, the reststrahlen effect is clearly seen. The dip in equivalent black body temperatures at 13 to 16 microns, especially at the higher altitudes is, of course, due to the 15 micron band of CO_2.

Following Figure 4 are all of the spectra covered in Table 1 in chronological order labeled with the Run Number, the Universal Time at which the spectra were taken and a number following the time denoting whether the spectrum was started in the first or second half of the minute.

THE MALPAIS (LAVA)

The Malpais consists of a lava flow approximately 30 miles in length, the southern end about 20 miles north of White Sands. The spectra are labeled "Oscura Lava" to distinguish this flow from others also called the Malpais. This flow is next to the Oscura Army Airstrip; hence, the choice of the name. The lava is pockmarked with roughly circular sinkholes most of which had green vegetation growing at the bottom.

Basalt, the common dark, heavy lava has one of the weakest reststrahlen of the various igneous rocks, and this fact coupled with the blackening due to the sinkholes would lead one to expect a weak reststrahlen. Laboratory measurements

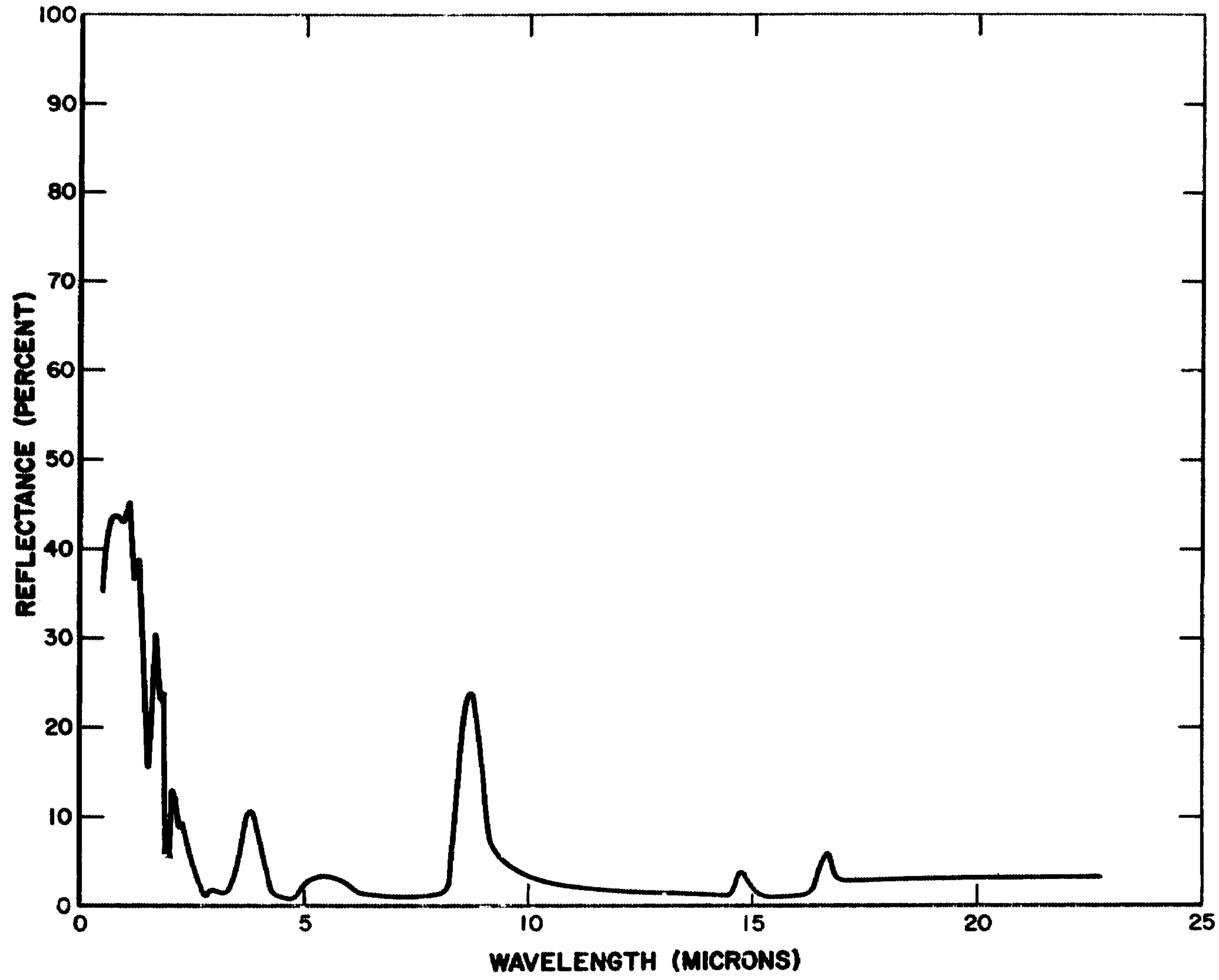
on basalt as shown in Figure 5 show a broad, rather weak reststrahlen that diminishes rapidly in intensity as the material is ground.

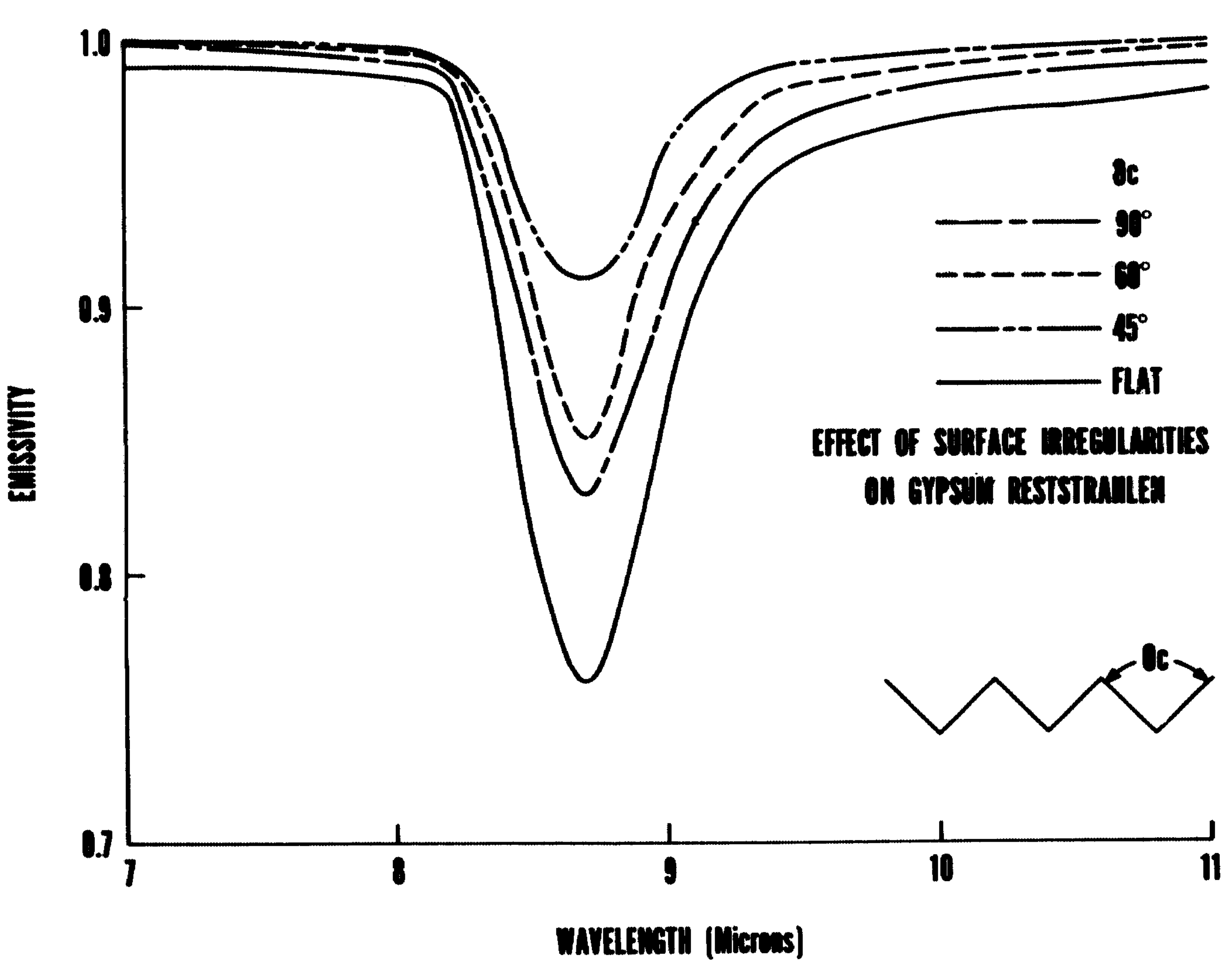
The measurements themselves shown in chronological order, following Table 2, show many apparent dips in equivalent black body temperature but none that can be consistently identified as due to reststrahlen. The spectral character seen is probably due to irregularity of the surface of the lava and the motion of the aircraft. This "noise" caused by a changing, non-uniform temperature pattern is apparently one of the most serious limitations on remote sensing of surface composition. It is clearly impossible to distinguish between a reduction in equivalent black body temperature at a particular wavelength due to a reststrahlen effect and variations in the spectra due to a change in the integrated temperature, caused by aircraft motion. Since the spectrometer is continually scanning, appearance of a hot or cold spot in the field of view will introduce spurious spectral features at whatever wavelength is being sensed at the time. This source of error argues strongly for the use of high spatial resolution, multichannel radiometers for surface composition determination. Since each wavelength interval is sensed simultaneously, looking at the same target area, the "motion noise" is reduced.

The flight path over the Malpais is shown in Figure 6.

REFERENCES

1. Hovis, W. A., Jr., W. A. Kley and M. G. Strange, Applied Optics, 6, 1057, (1967)


100
90
80
70
60
50
40
30
20
10
0
REFLECTANCE (PERCENT)
0
5
10
15
20
25
WAVELENGTH (MICRONS)
Figure 1



1.0
0.9
0.8
0.7
EMISSIVITY
7
8
9
10
11
WAVELENGTH (Microns)
θc
90°
60°
45°
FLAT
EFFECT OF SURFACE IRREGULARITIES
ON GYPSUM RESTSTRAHLEN
θc

Figure 2

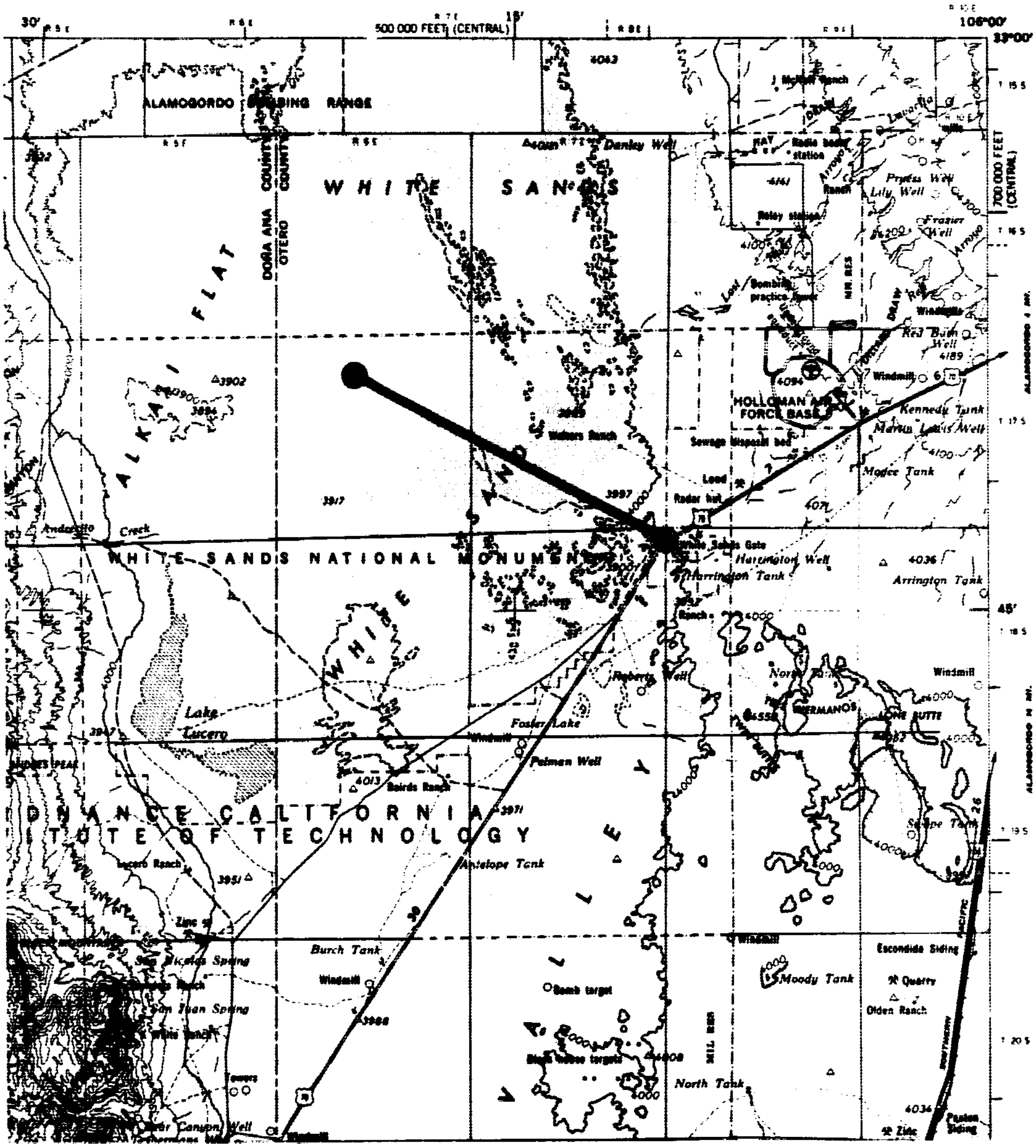
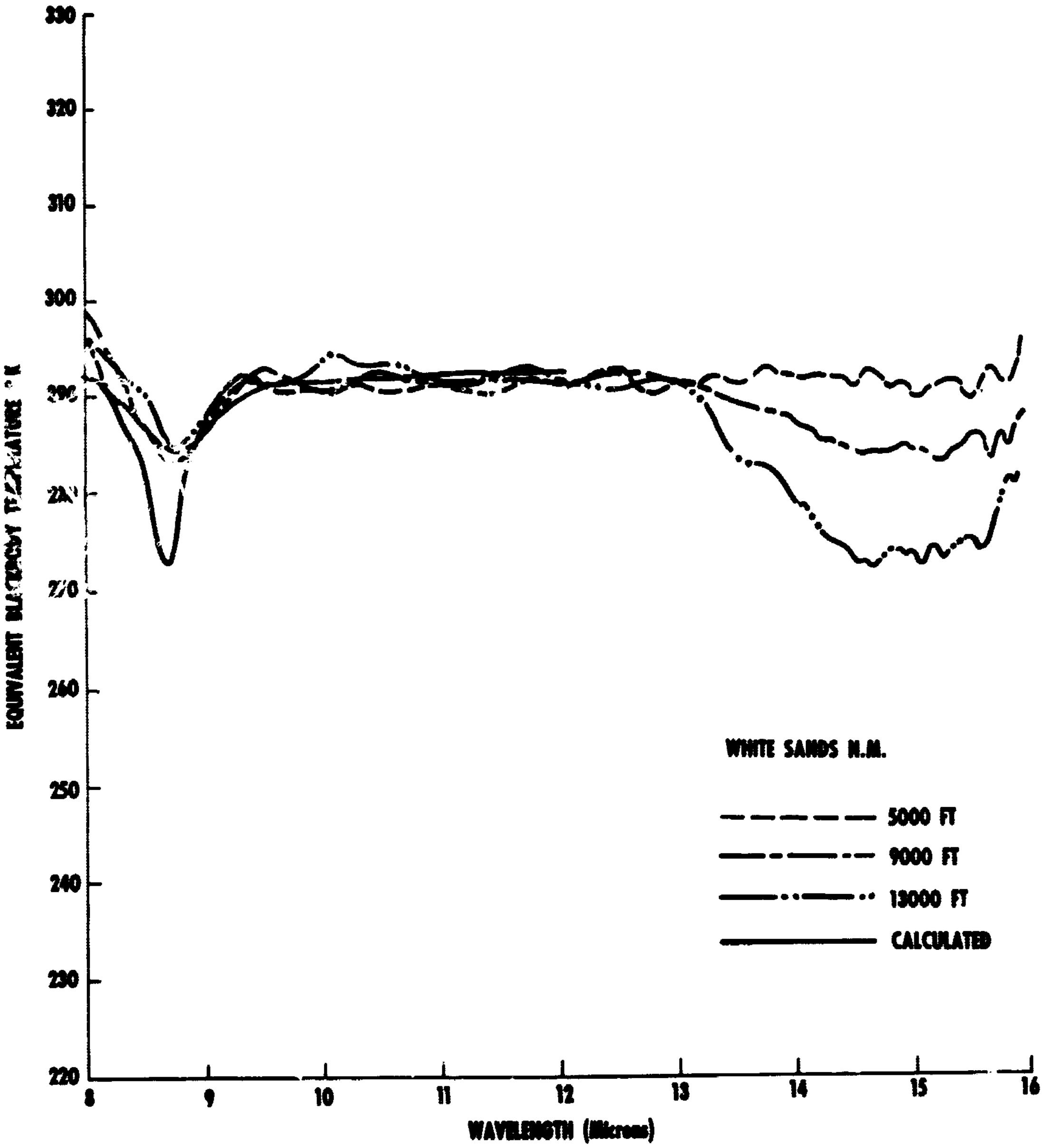

ALAMOGORDO BOMBING RANGE
WHITE SANDS
ALKALI FLAT
DOÑA ANA COUNTY
OTERO COUNTY
HOLLOMAN AIR FORCE BASE
WHITE SANDS NATIONAL MONUMENT
Lake Lucero
CALIFORNIA INSTITUTE OF TECHNOLOGY
VALLEY
500 000 FEET (CENTRAL)
700 000 FEET (CENTRAL)
106°00'
33°00'
45'
30'
15'

Figure 3

Table 1

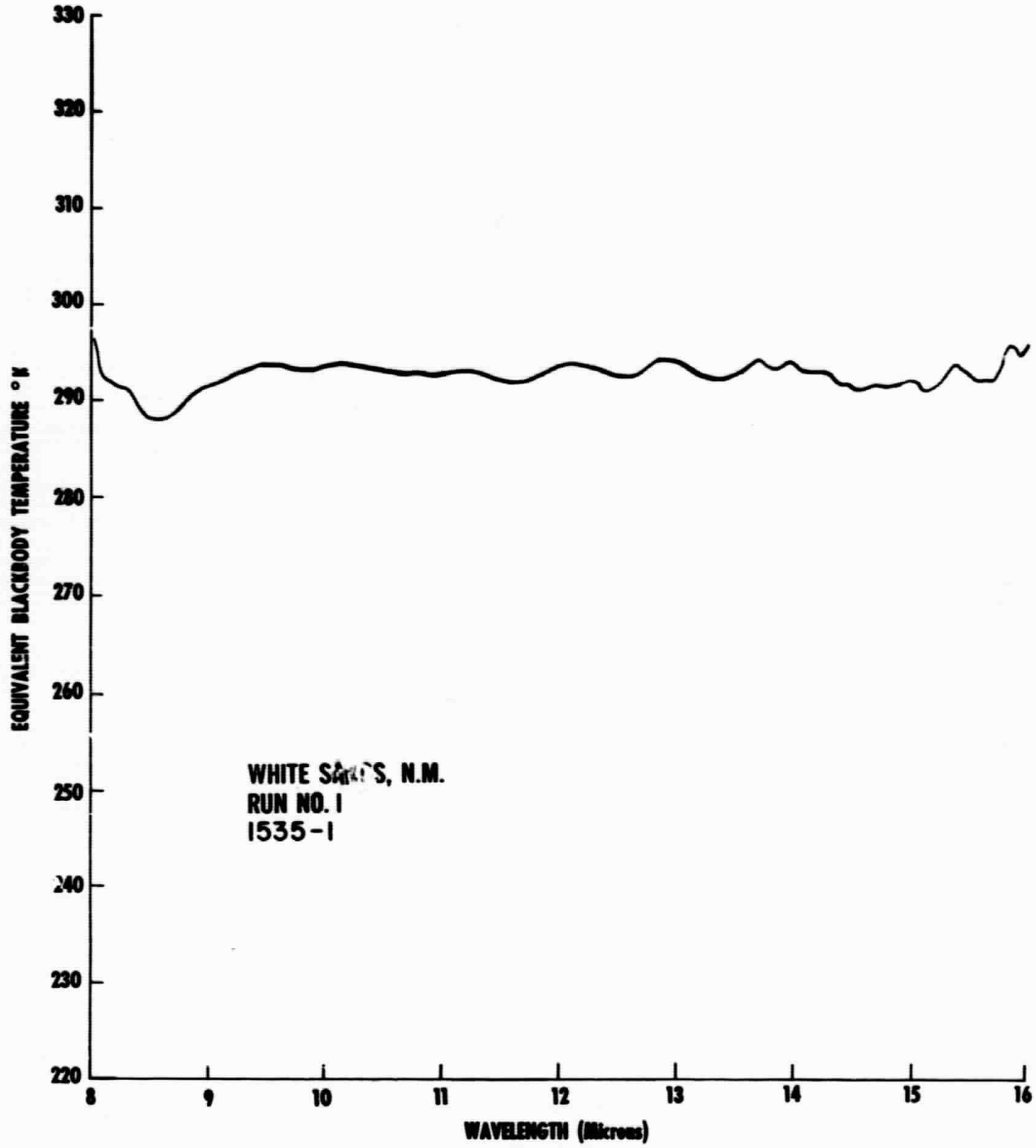
Aircraft: C47 NASA 636 Date: Oct 15, 1967
Target: White Sands N.M. Instrument: . F.W.S. 8 to 16 Microus

Run Number	Time (U.T.)	Altitude (kft)	Outside Temp. °C	Remarks
1	1535 1539	5	14	West to East
2	1542 1545	5	14	East to West
3	1551 1553	7	10	West to East
4	1557 1601	7	10	East to West
5	1607 1610	9	7	West to East
6	1613 1617	9	7	East to West
7	1622 1626	11	5	West to East
8	1628 1633	11	5	East to West
9	1638 1640	13	0	West to East
10	1643 1647	13	0	East to West

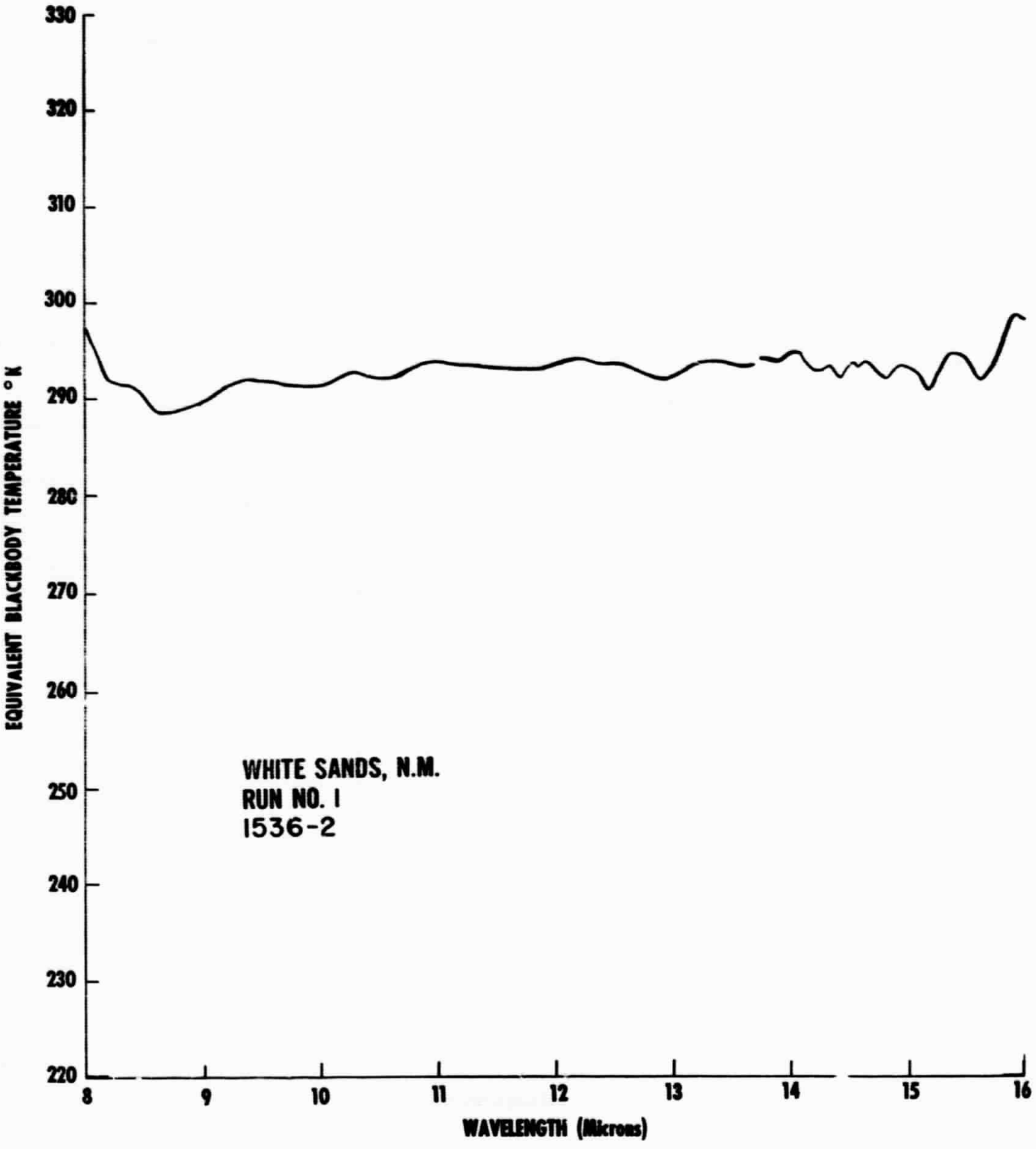


WHITE SANDS N.M.
5000 FT
9000 FT
13000 FT
CALCULATED
WAVELENGTH (Microns)

Figure 4



330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 1
1535-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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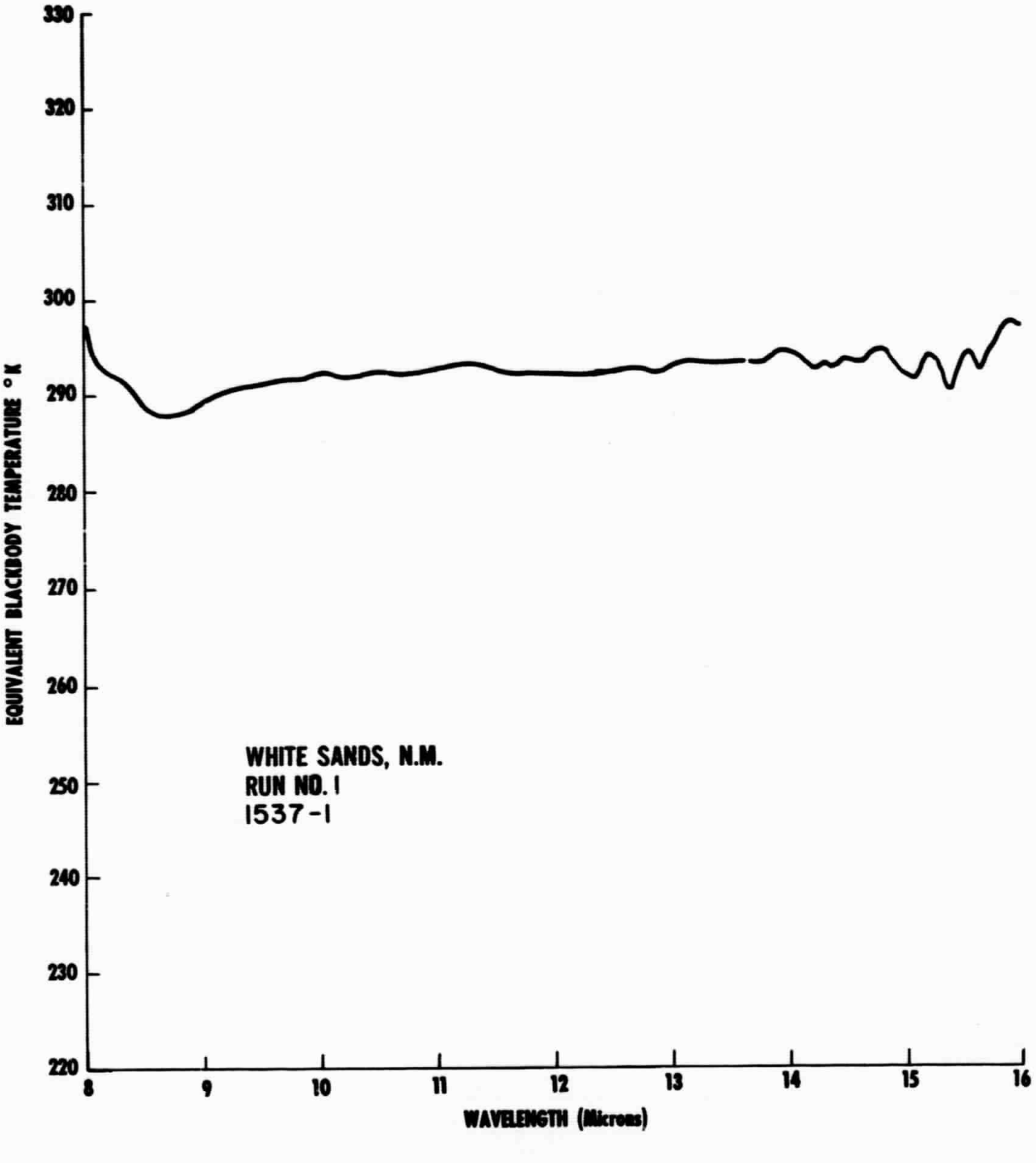
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 1
1536-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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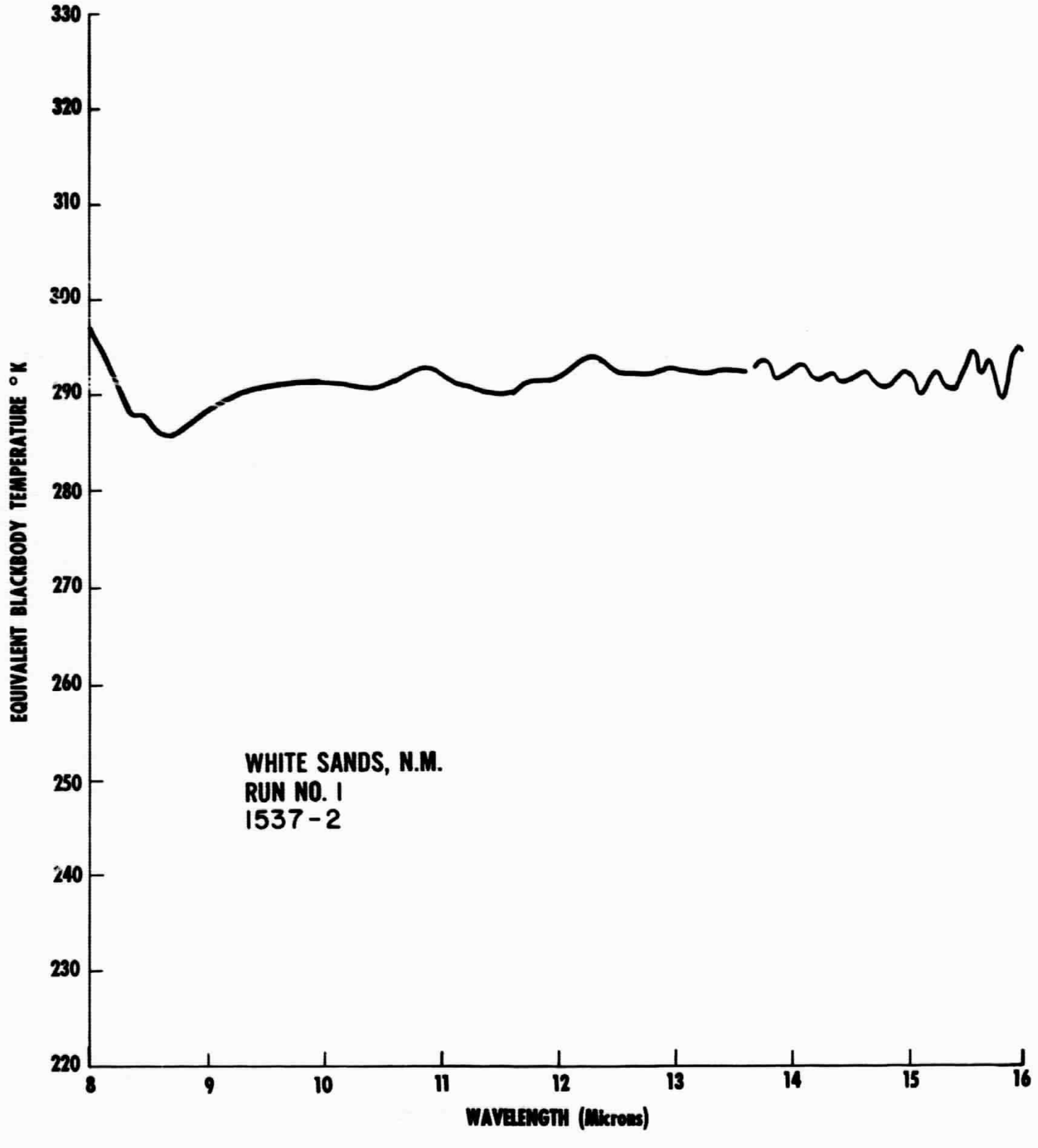
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 1
1537-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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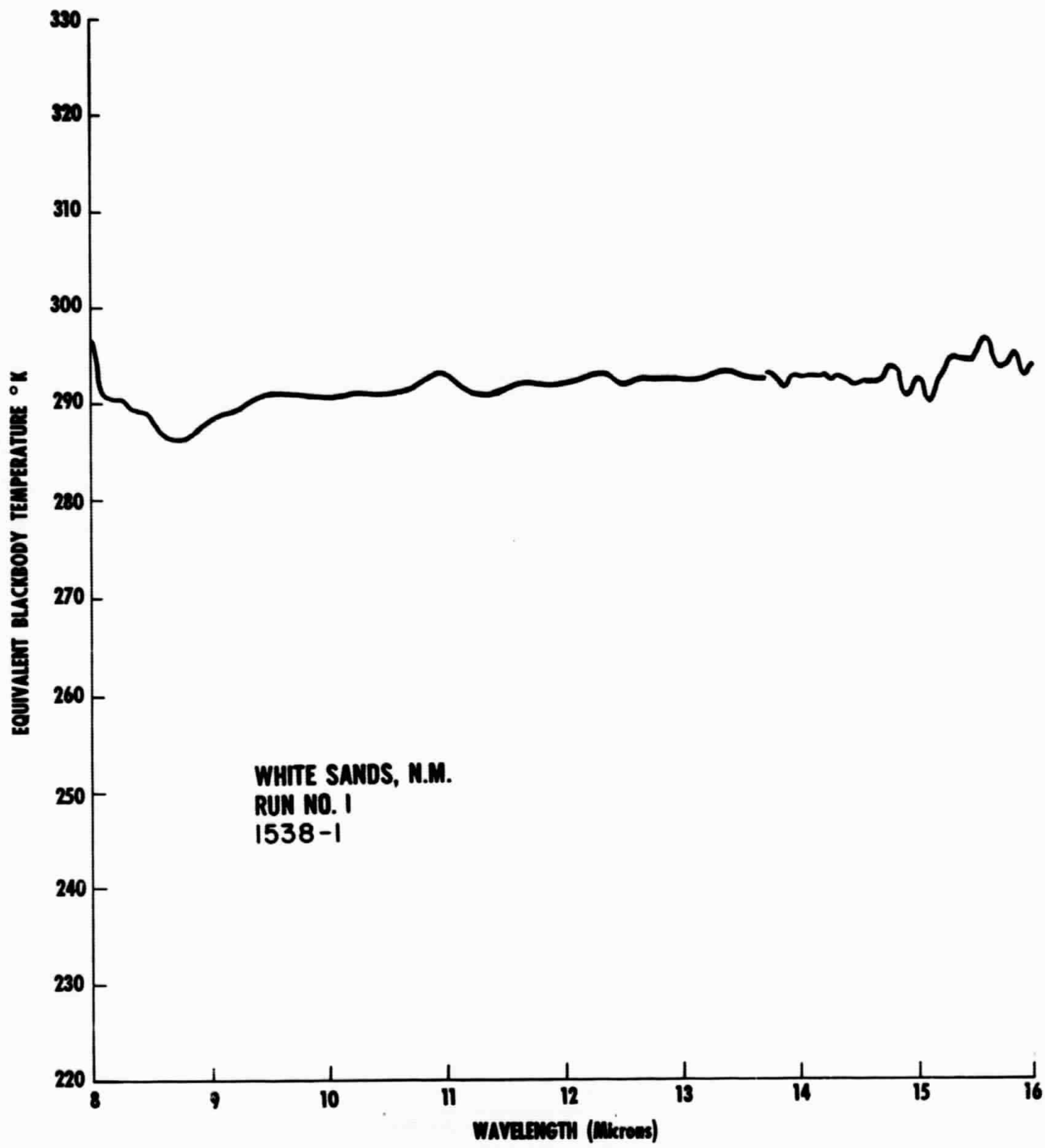
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 1
1537-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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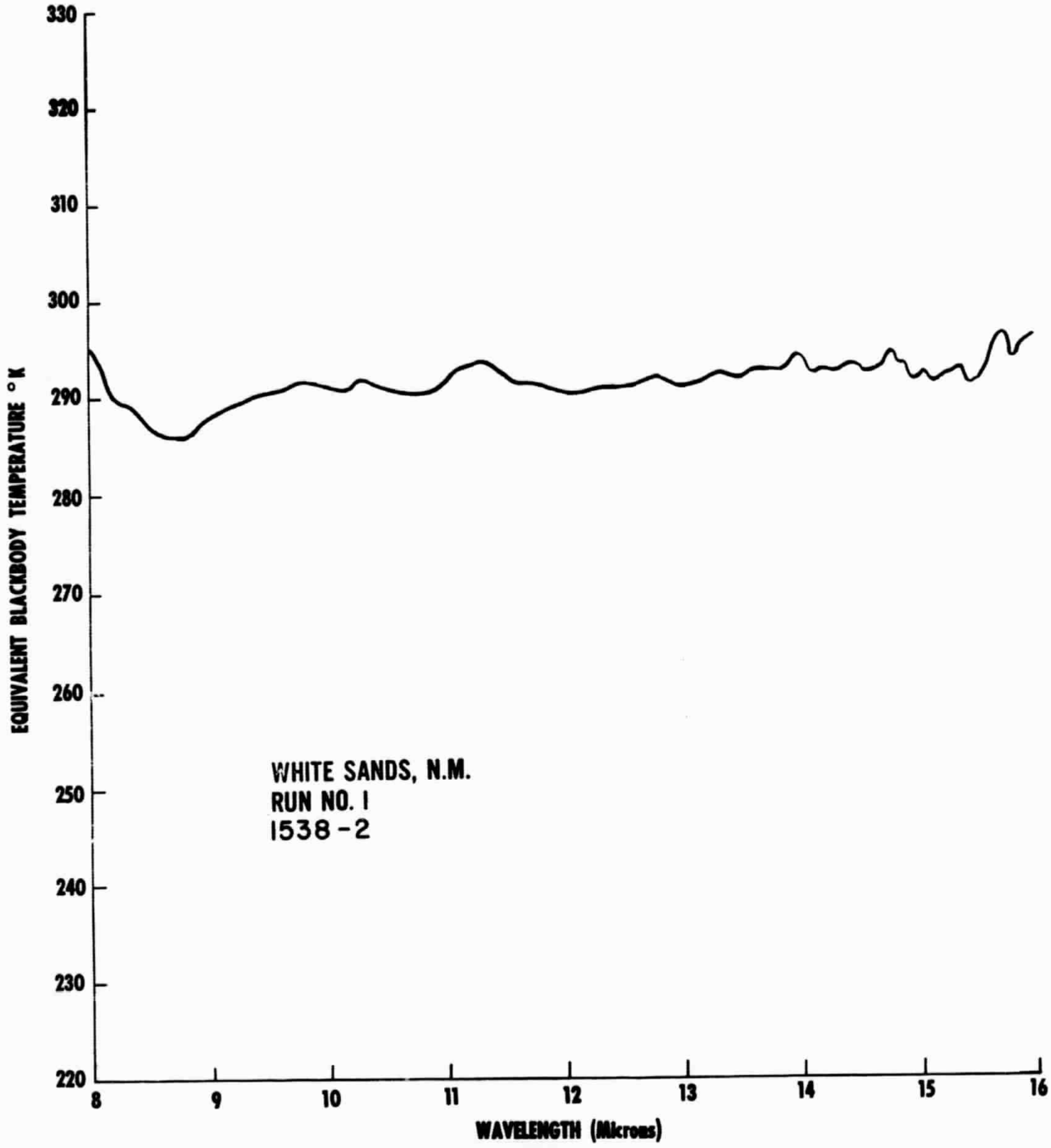
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 1
1538-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
300
290
280
270
260
250
240
230
220
WHITE SANDS, N.M.
RUN NO. 1
1538-2
8
9
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12
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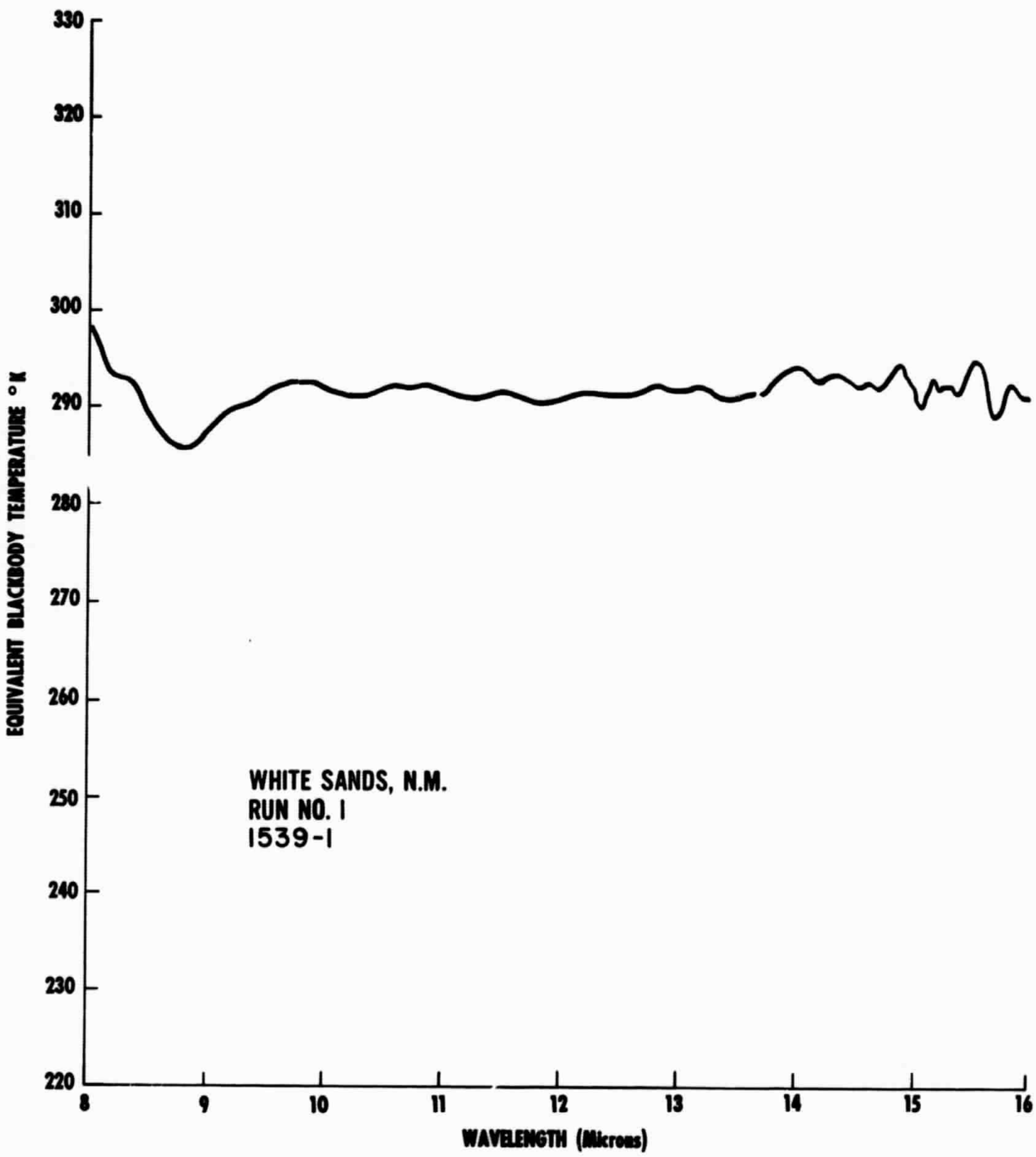
14
15
16
WAVELENGTH (Microns)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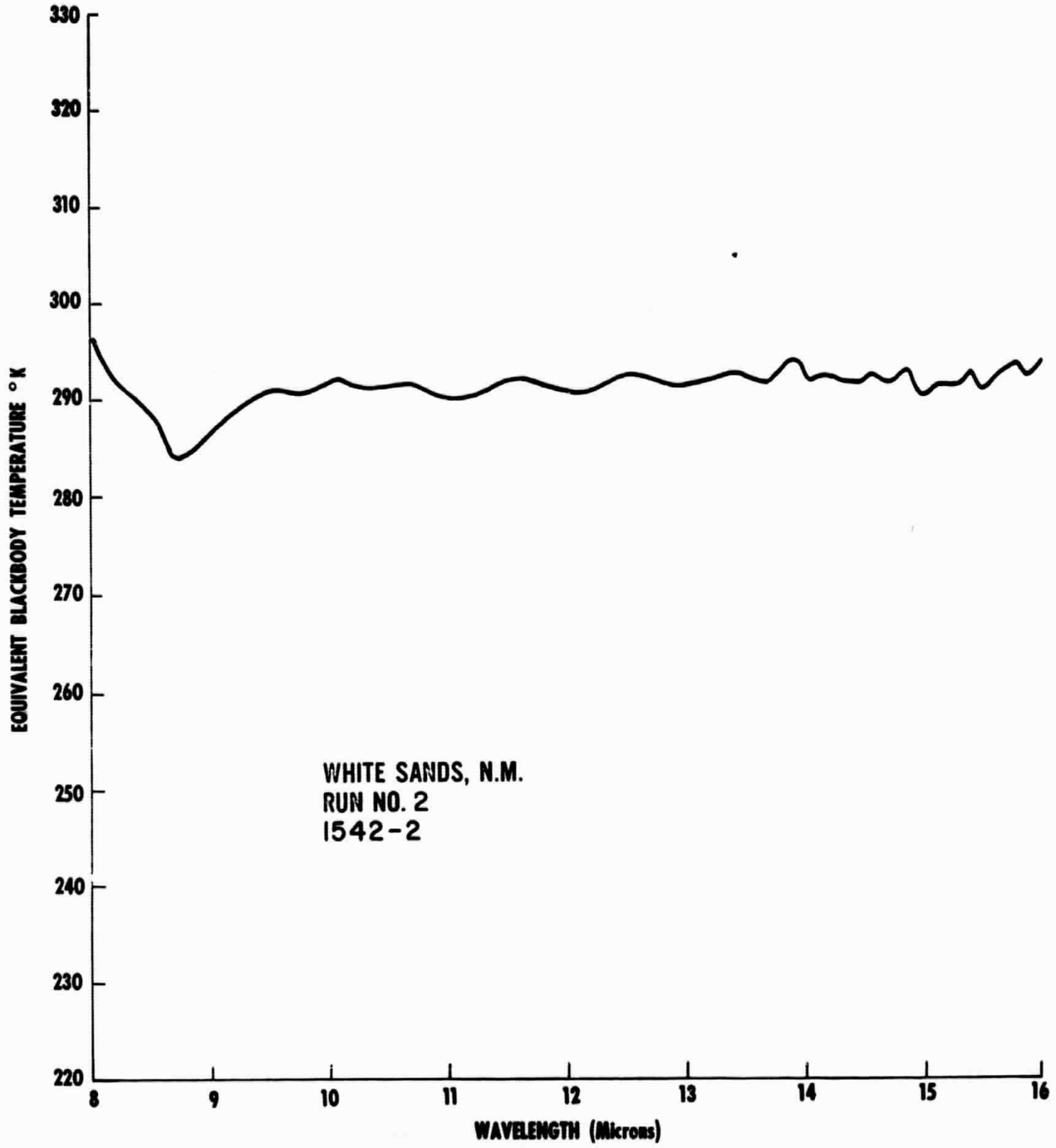
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 1
1539-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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320
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250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 2
1542-2
8
9
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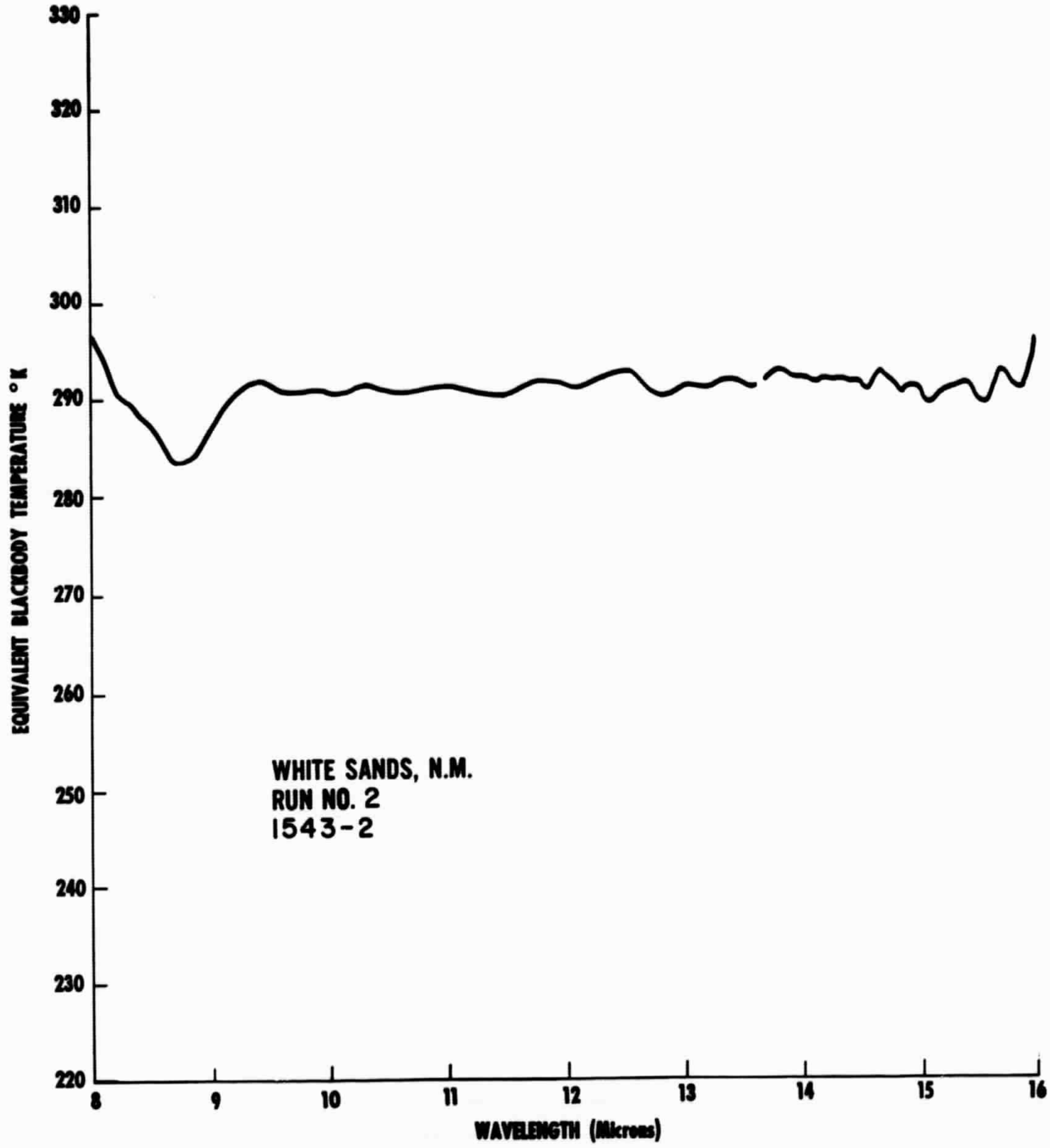
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
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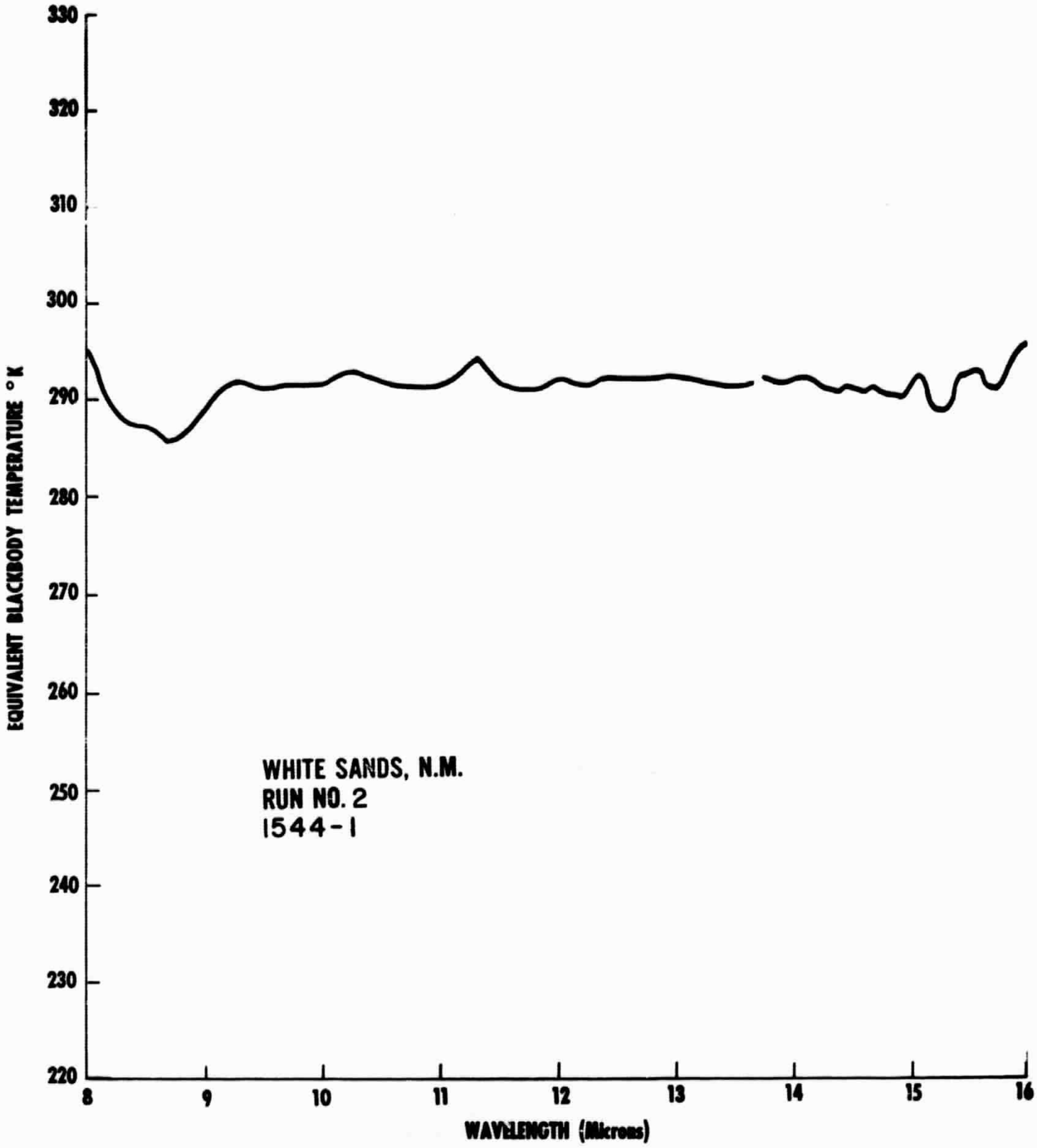
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 2
1543-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)



EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
300
290
280
270
260
250
240
230
220
8
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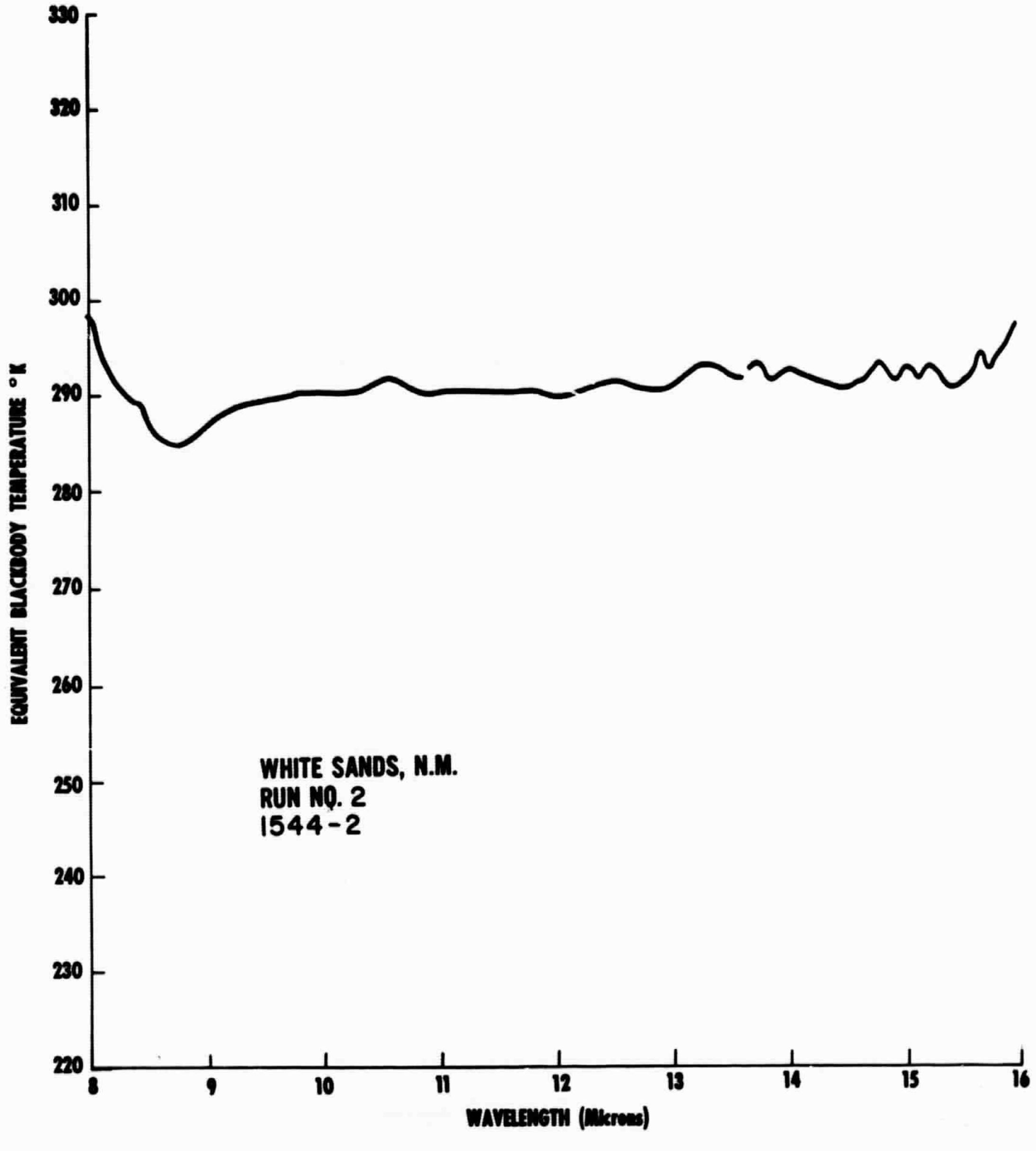
13
14
15
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 2
1544-1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320
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260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 2
1544-2
8
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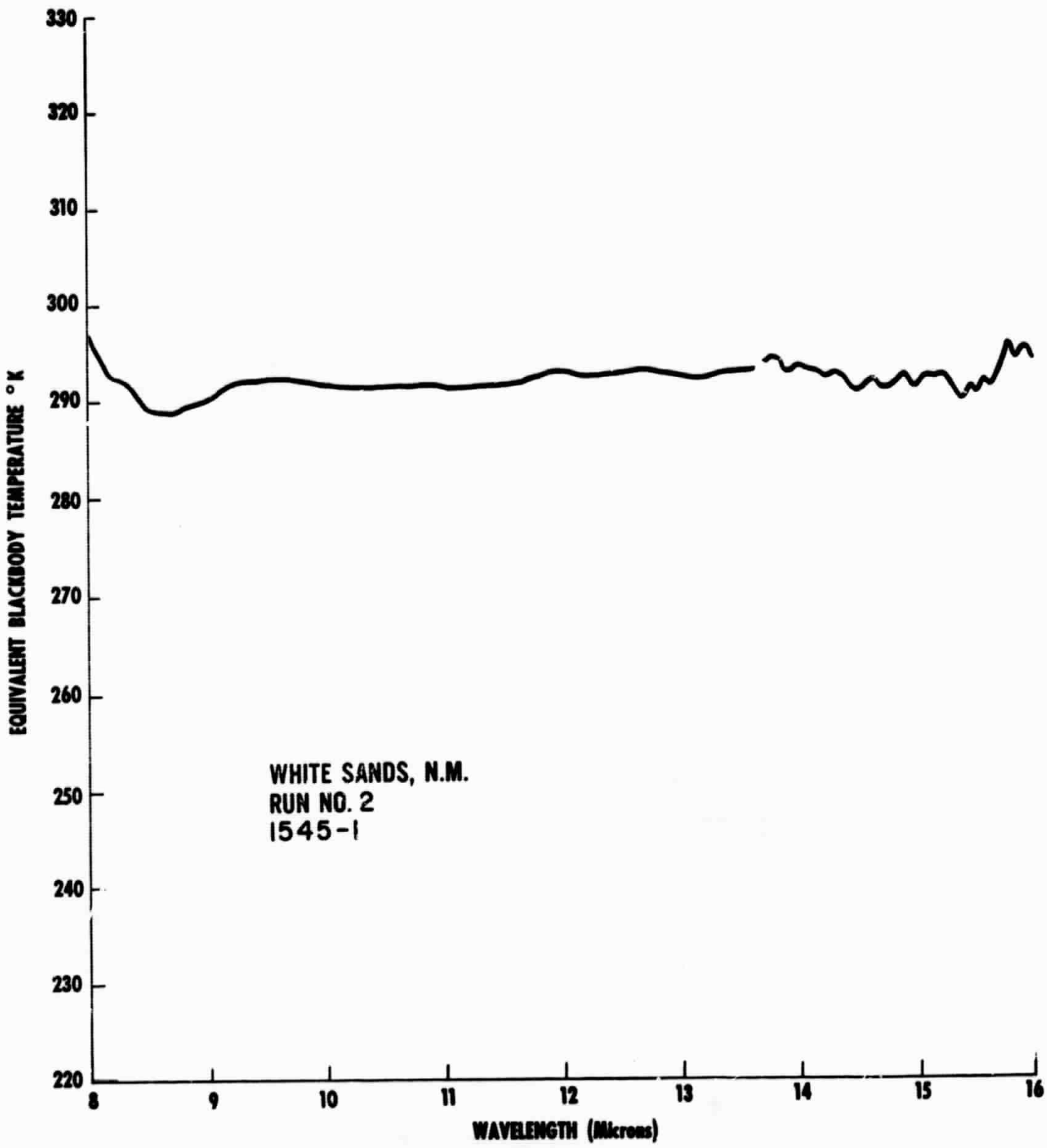
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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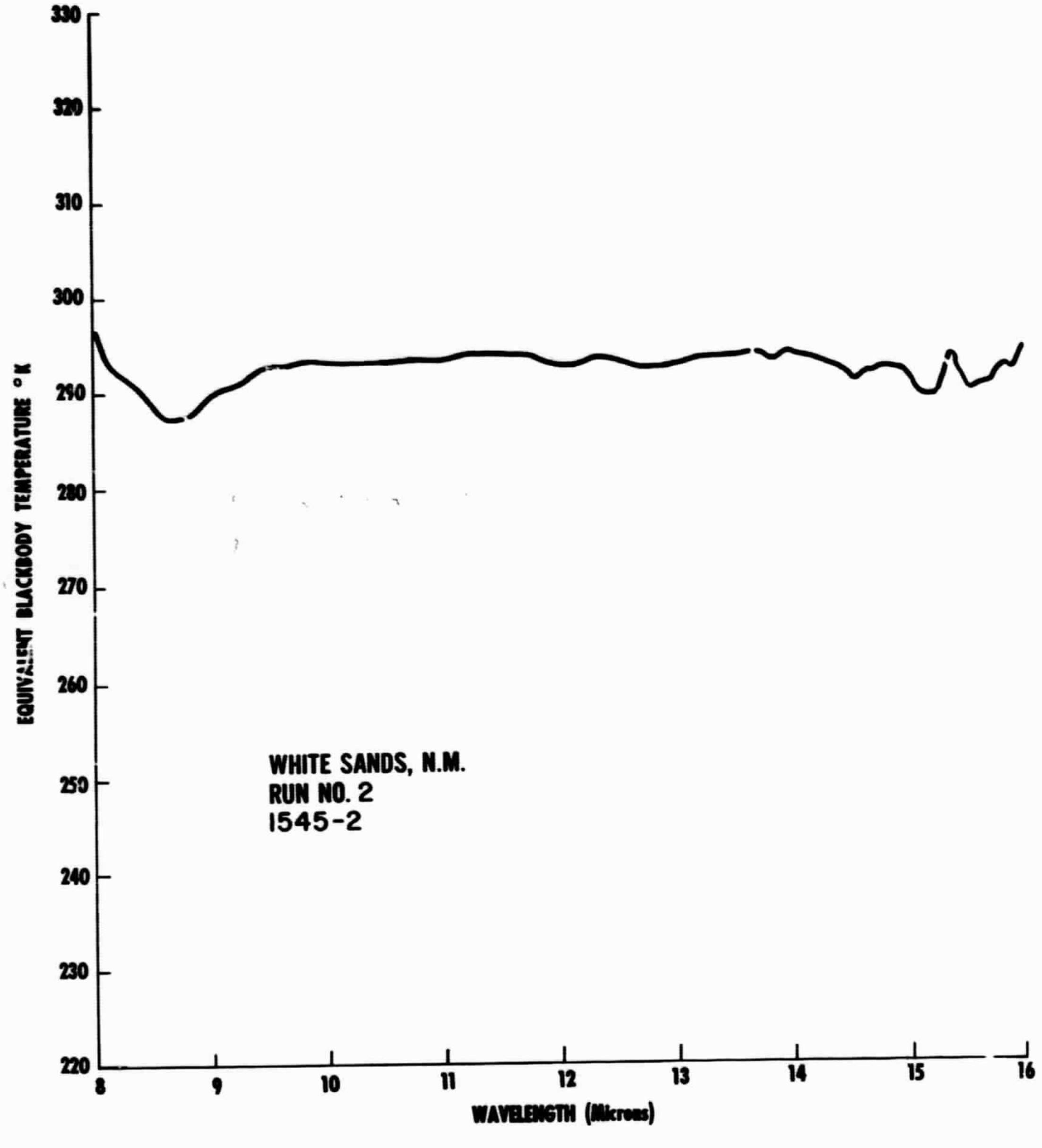
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 2
1545-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 2
1545-2
8
9
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14
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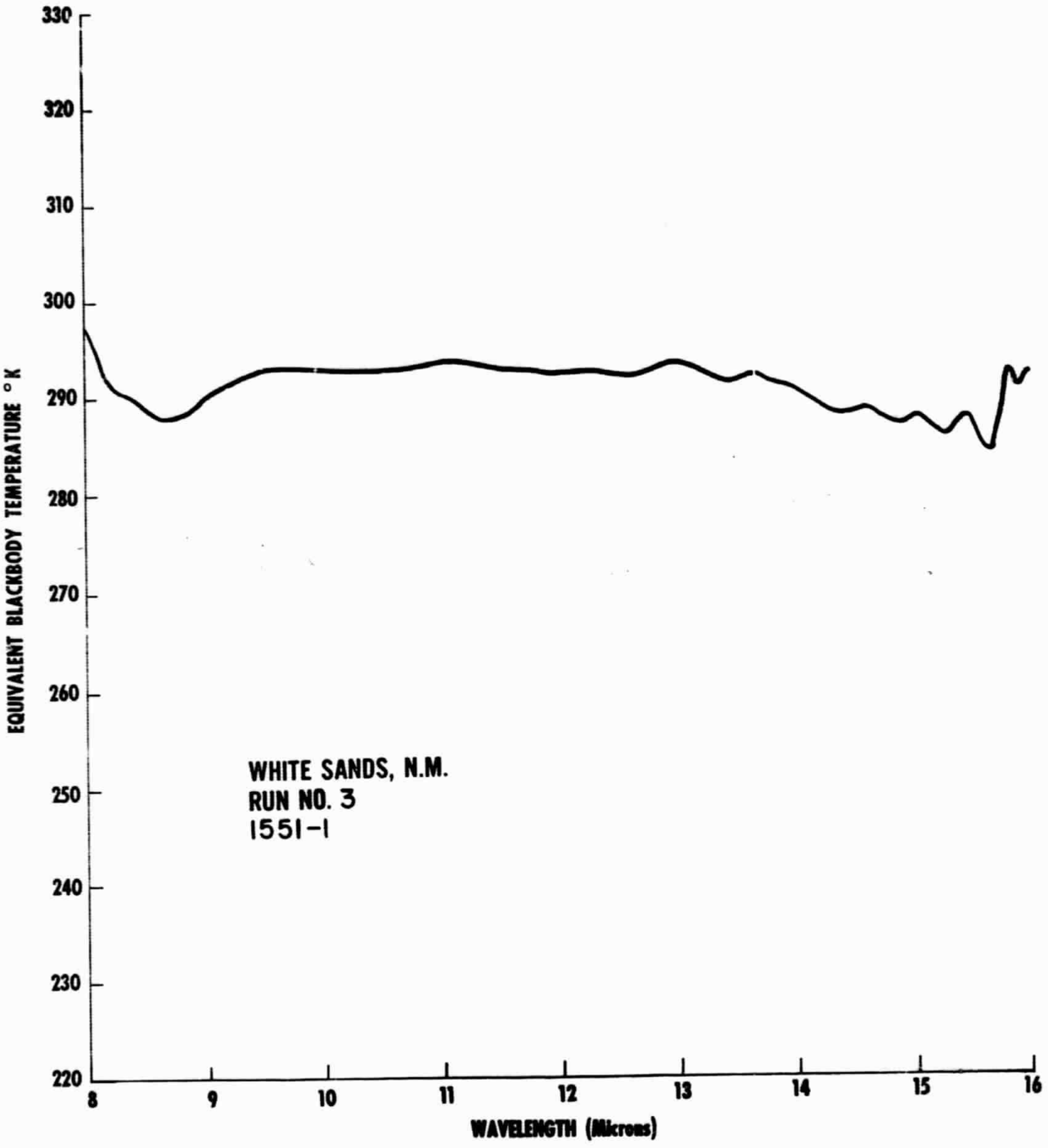
16
WAVELENGTH (Microns)


330
320
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230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 3
1551-1
8
9
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11
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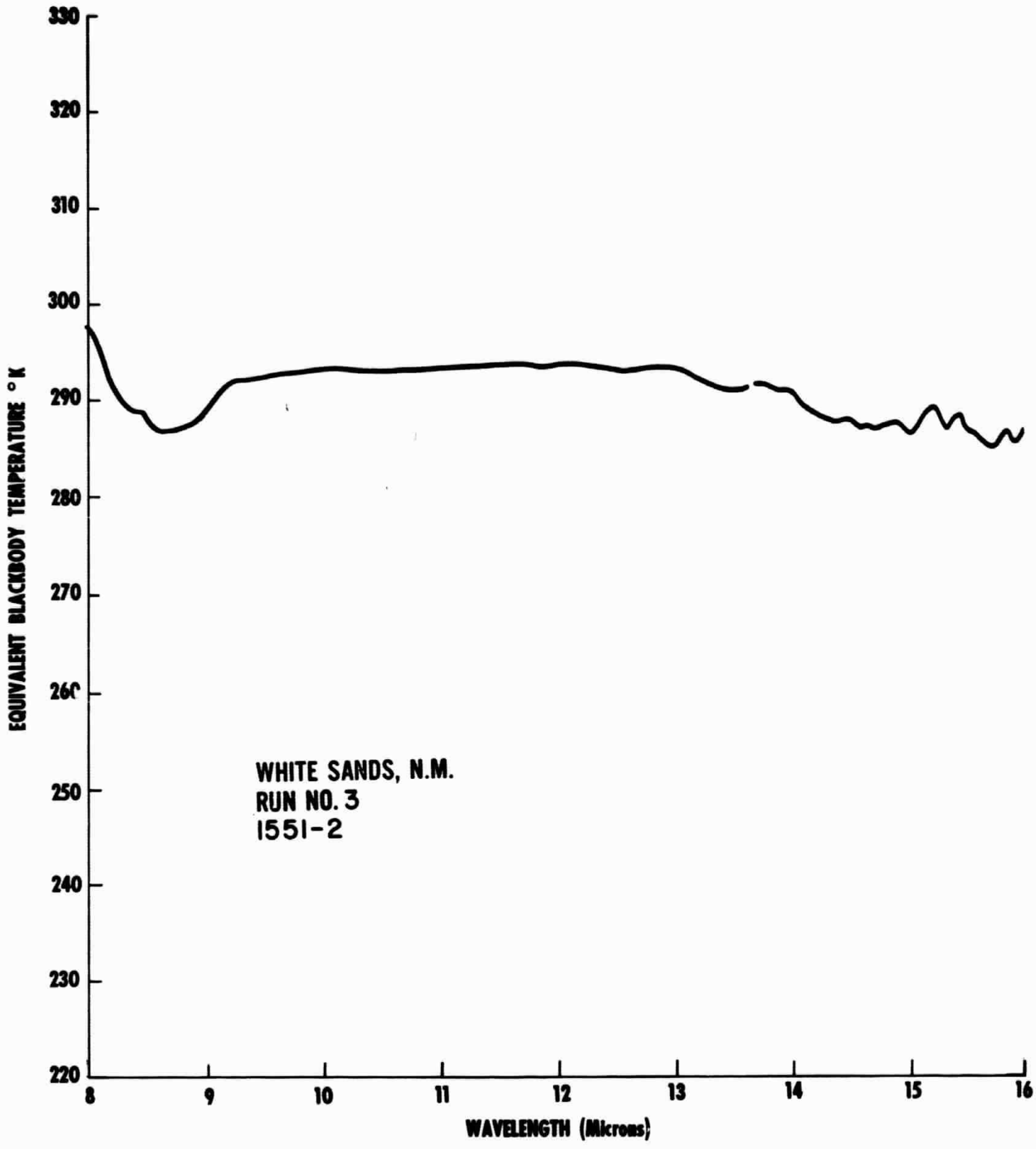
14
15
16
WAVELENGTH (Microns)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330
320
310
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280
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250
240
230
220
WHITE SANDS, N.M.
RUN NO. 3
1551-2
8
9
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14
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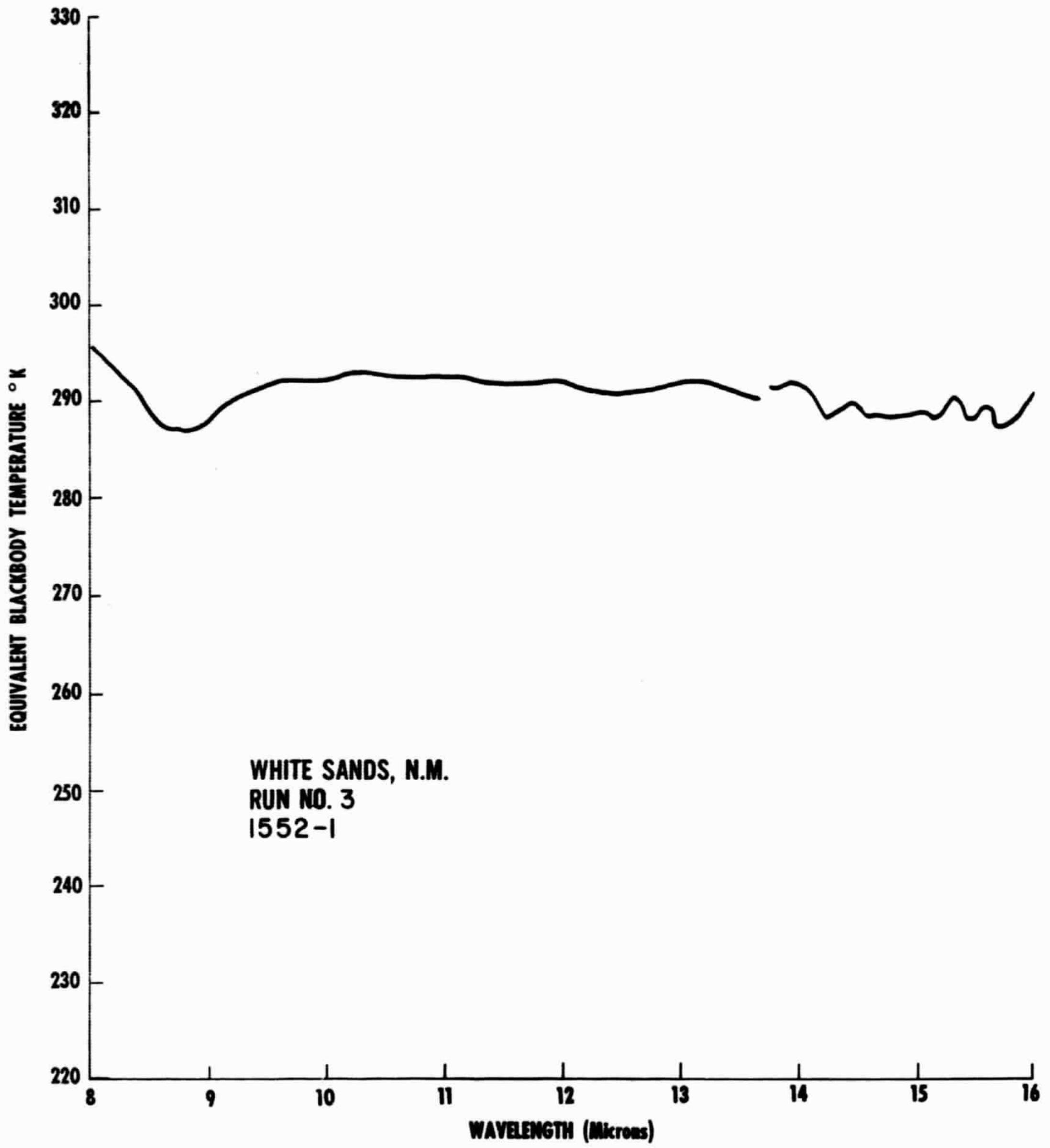
16
WAVELENGTH (Microns)


330
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270
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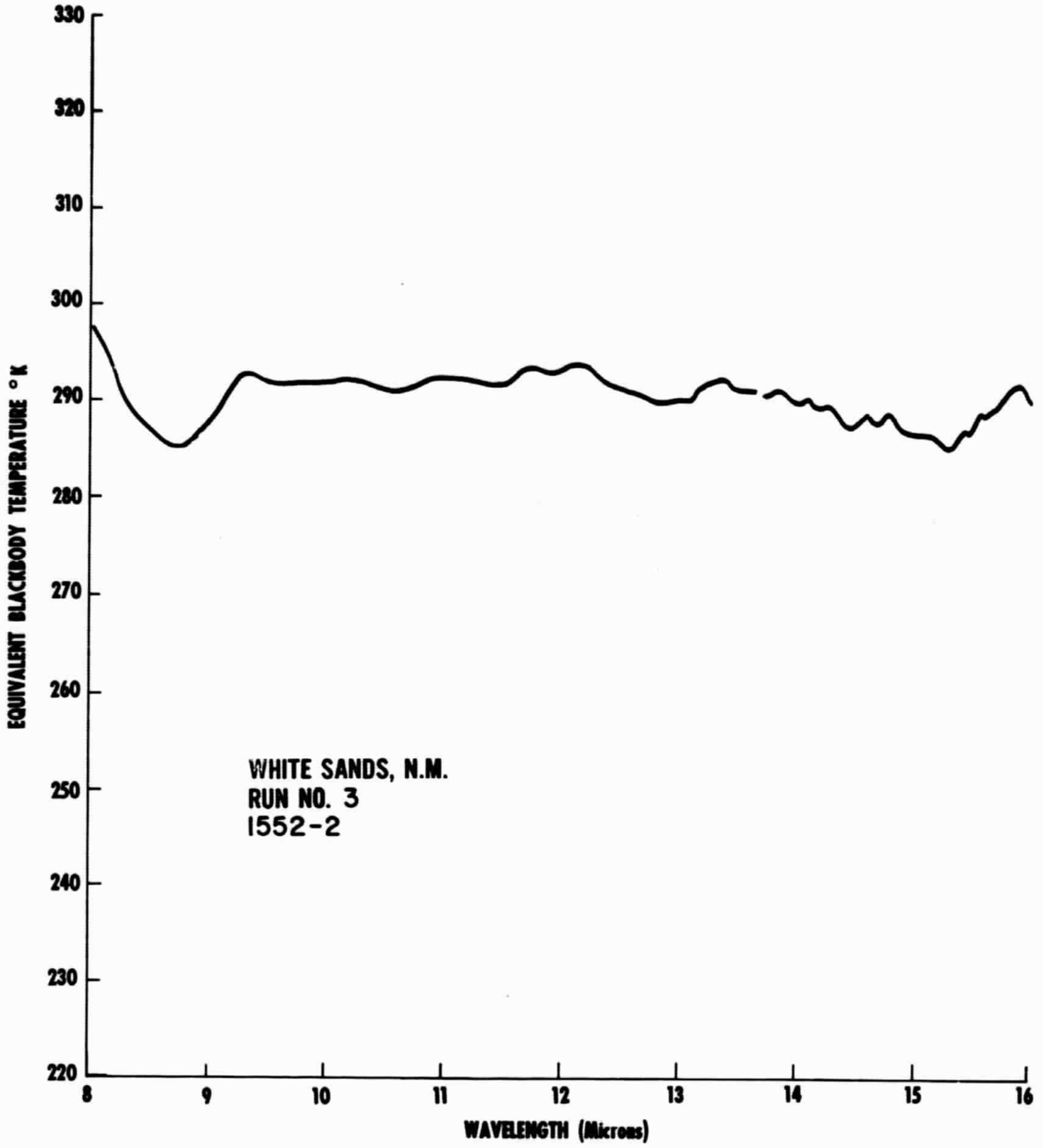
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 3
1552-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
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220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 3
1552-2
8
9
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11
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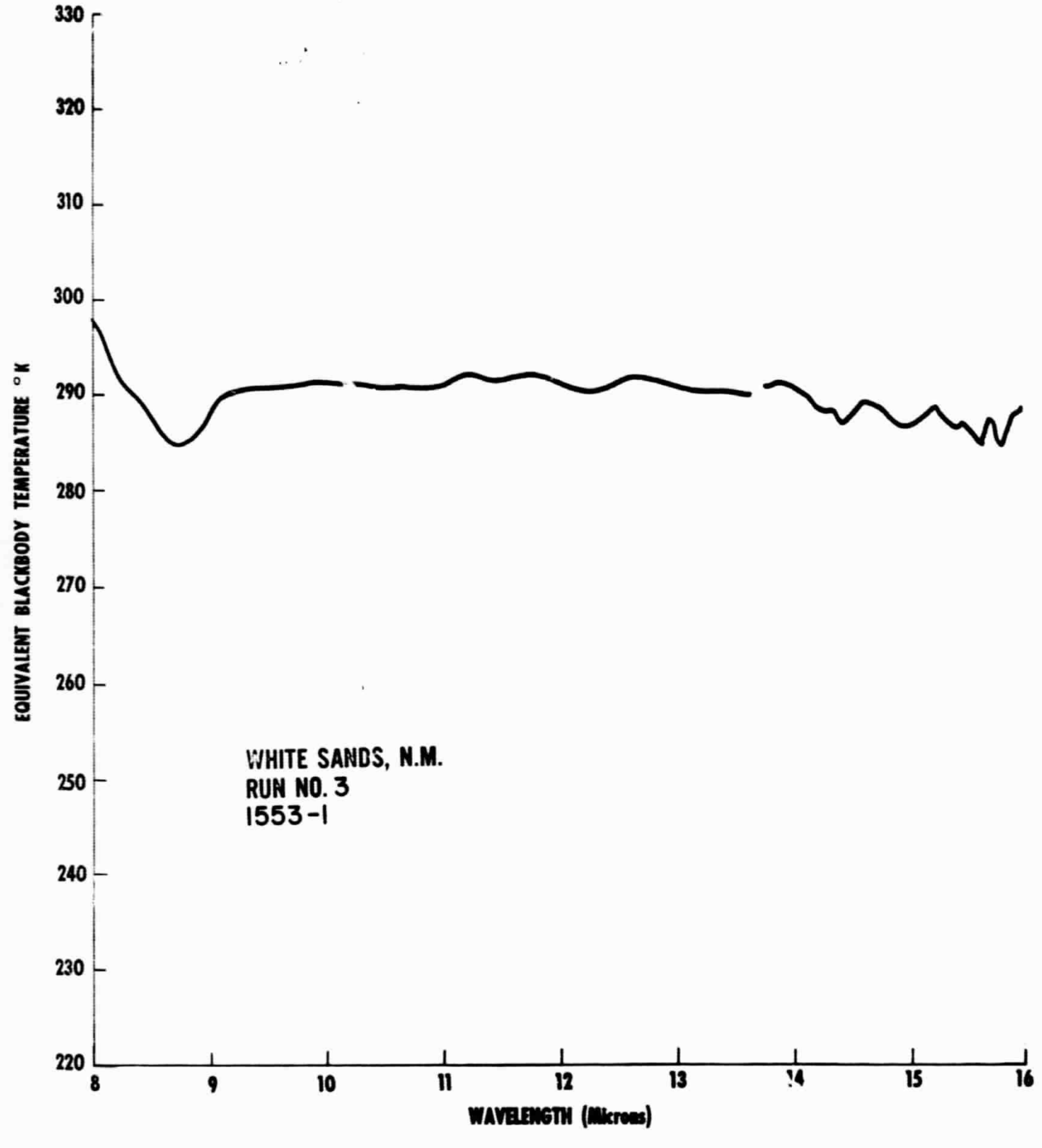
14
15
16
WAVELENGTH (Microns)


EQUIVALENT BLACKBODY TEMPERATURE °K
330
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290
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240
230
220
WHITE SANDS, N.M.
RUN NO. 3
1553-1
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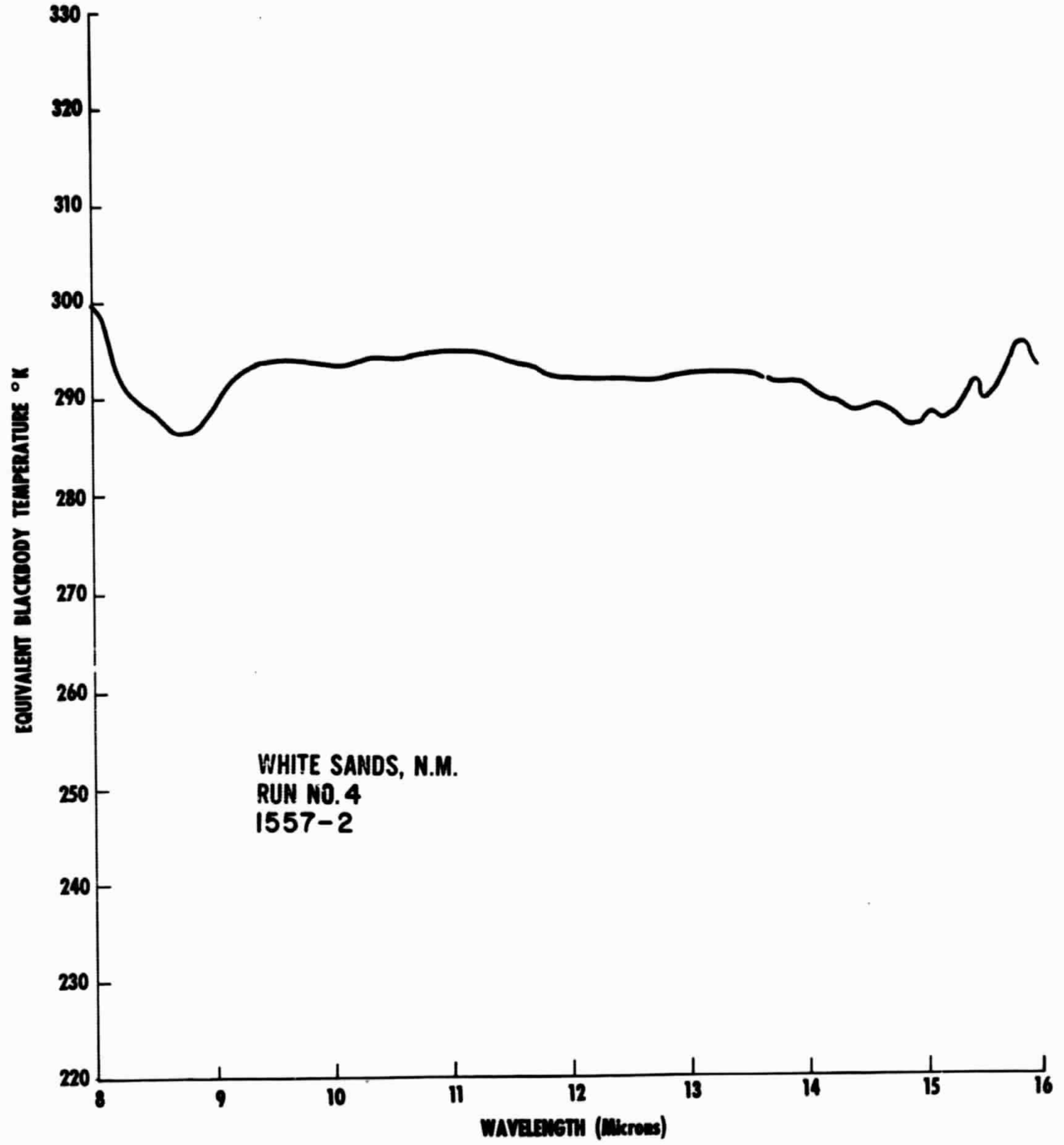
16
WAVELENGTH (Microns)


330
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230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
8
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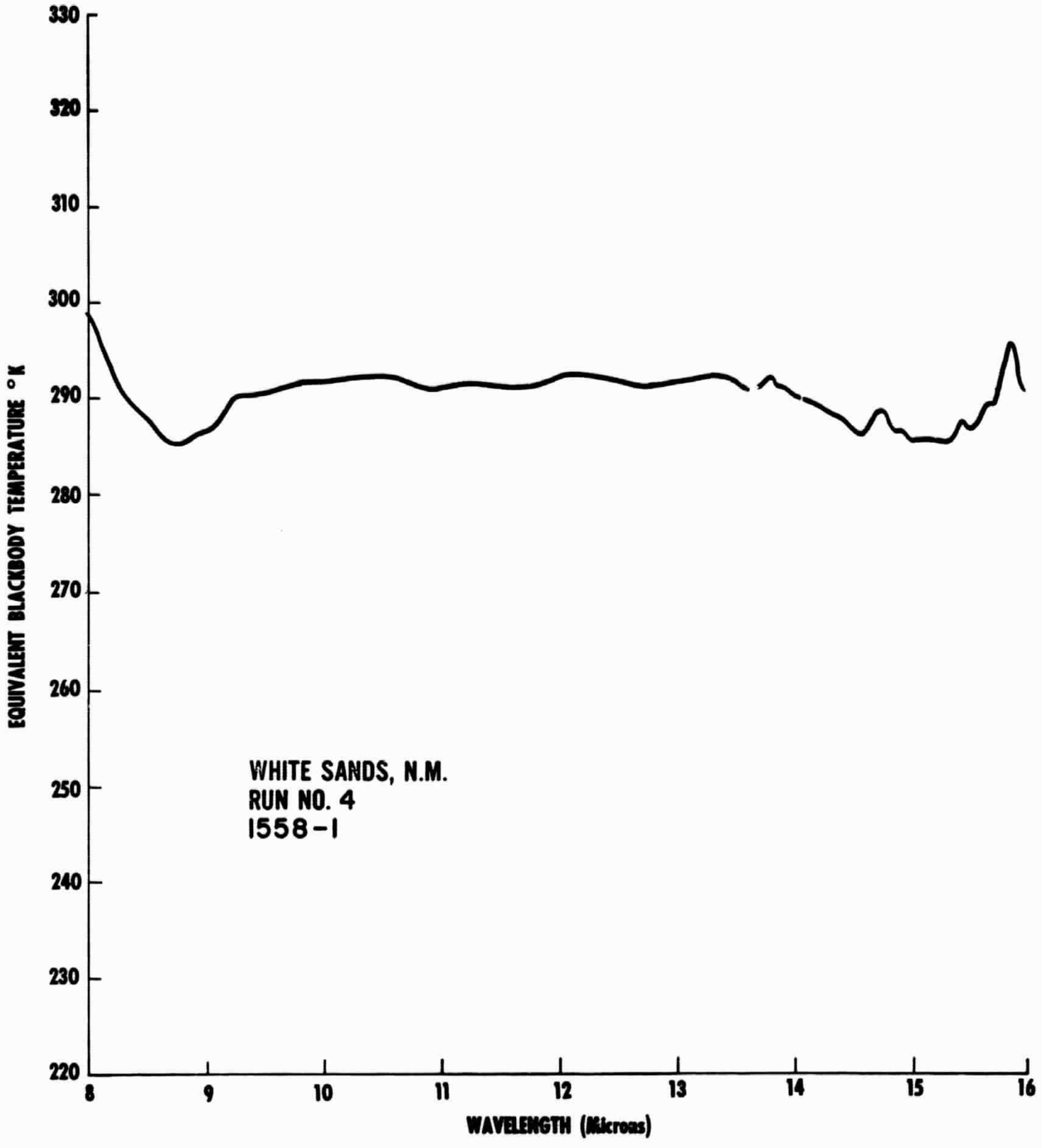
14
15
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 4
1557-2


330
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230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 4
1558-1
8
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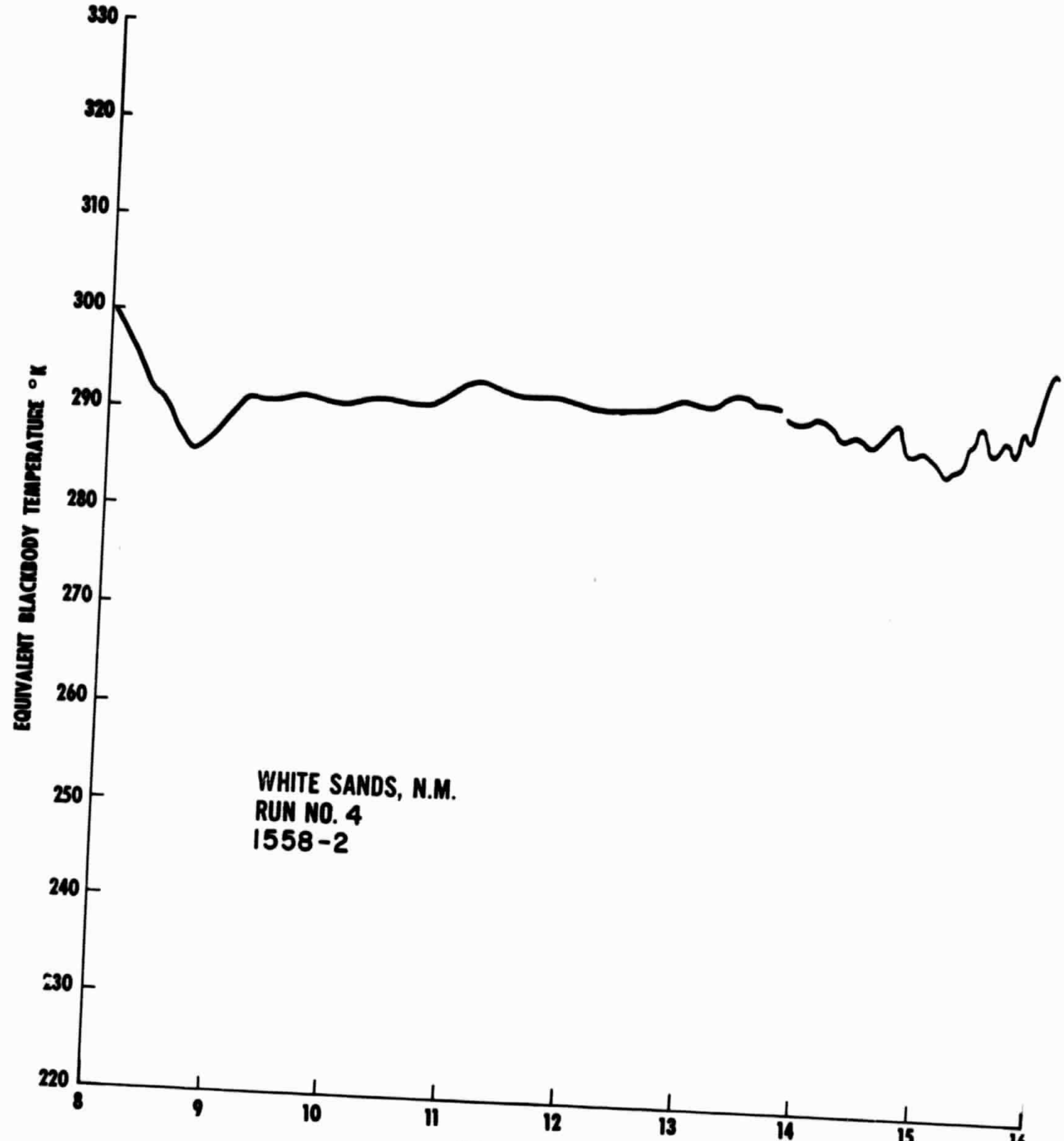
14
15
16
WAVELENGTH (Microns)


EQUIVALENT BLACKBODY TEMPERATURE °K
330
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280
270
260
250
240
230
220
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11
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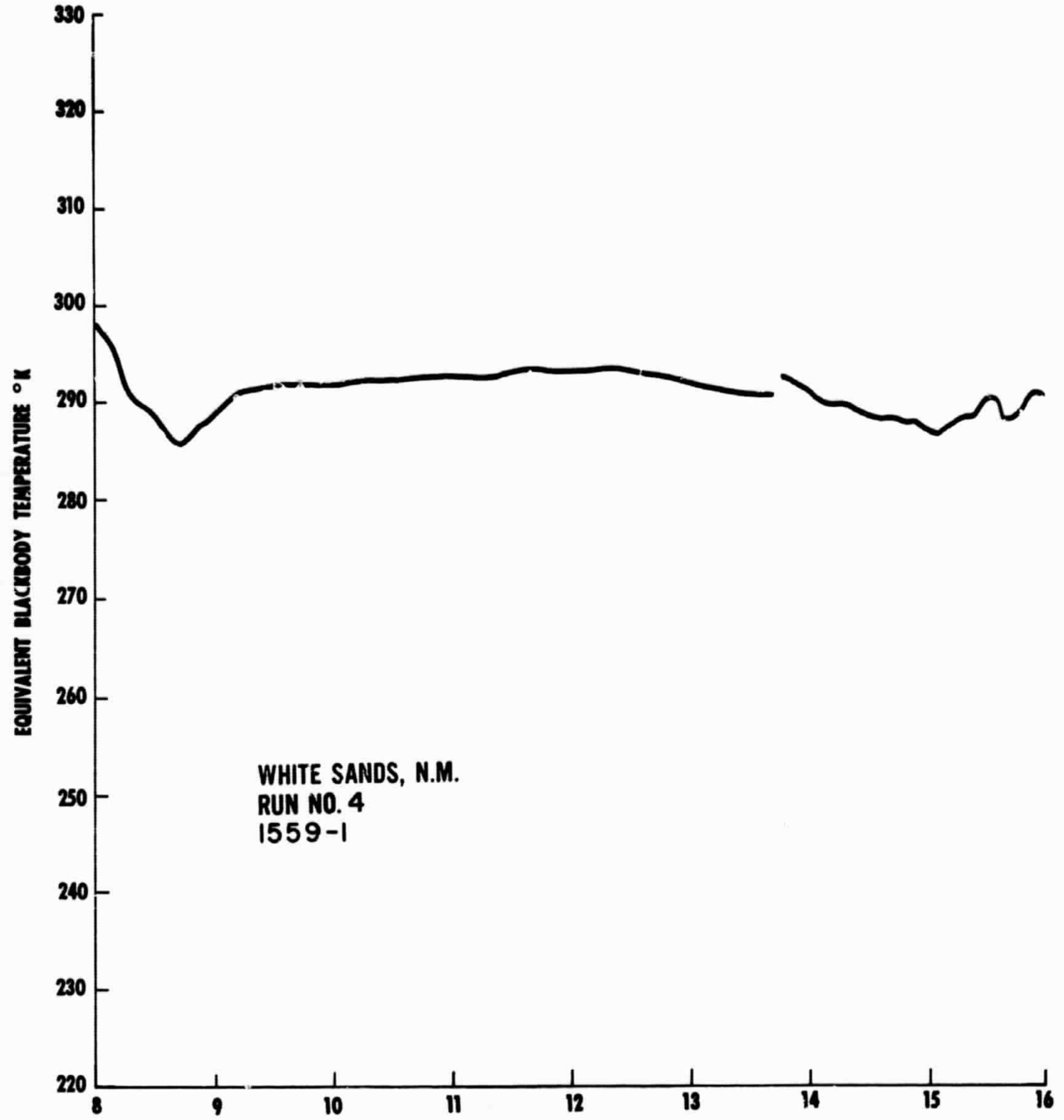
13
14
15
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 4
1558-2


EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
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290
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270
260
250
240
230
220
WHITE SANDS, N.M.
RUN NO. 4
1559-1
8
9
10
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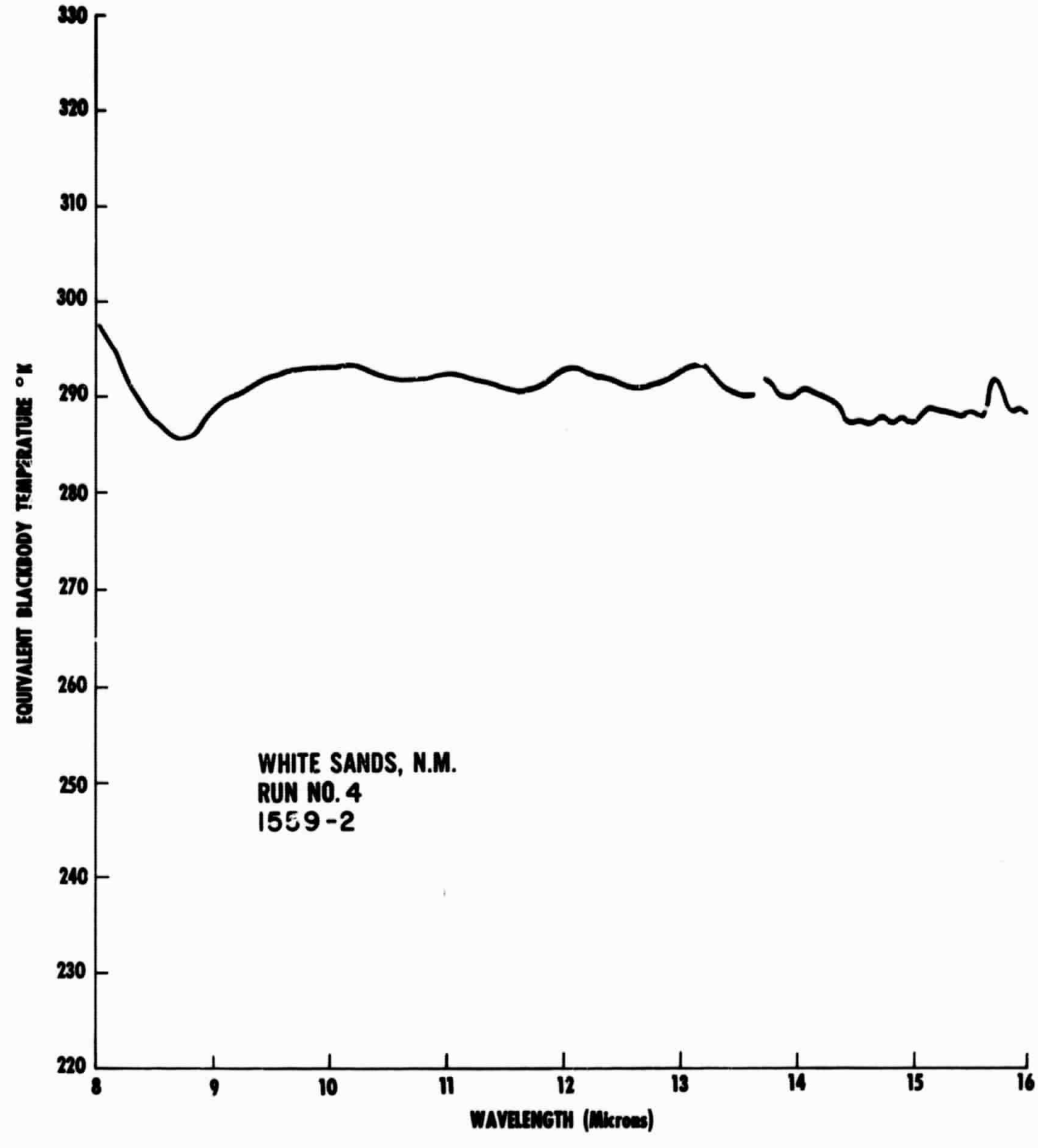
13
14
15
16
WAVELENGTH (Microns)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330
320
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230
220
8
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13
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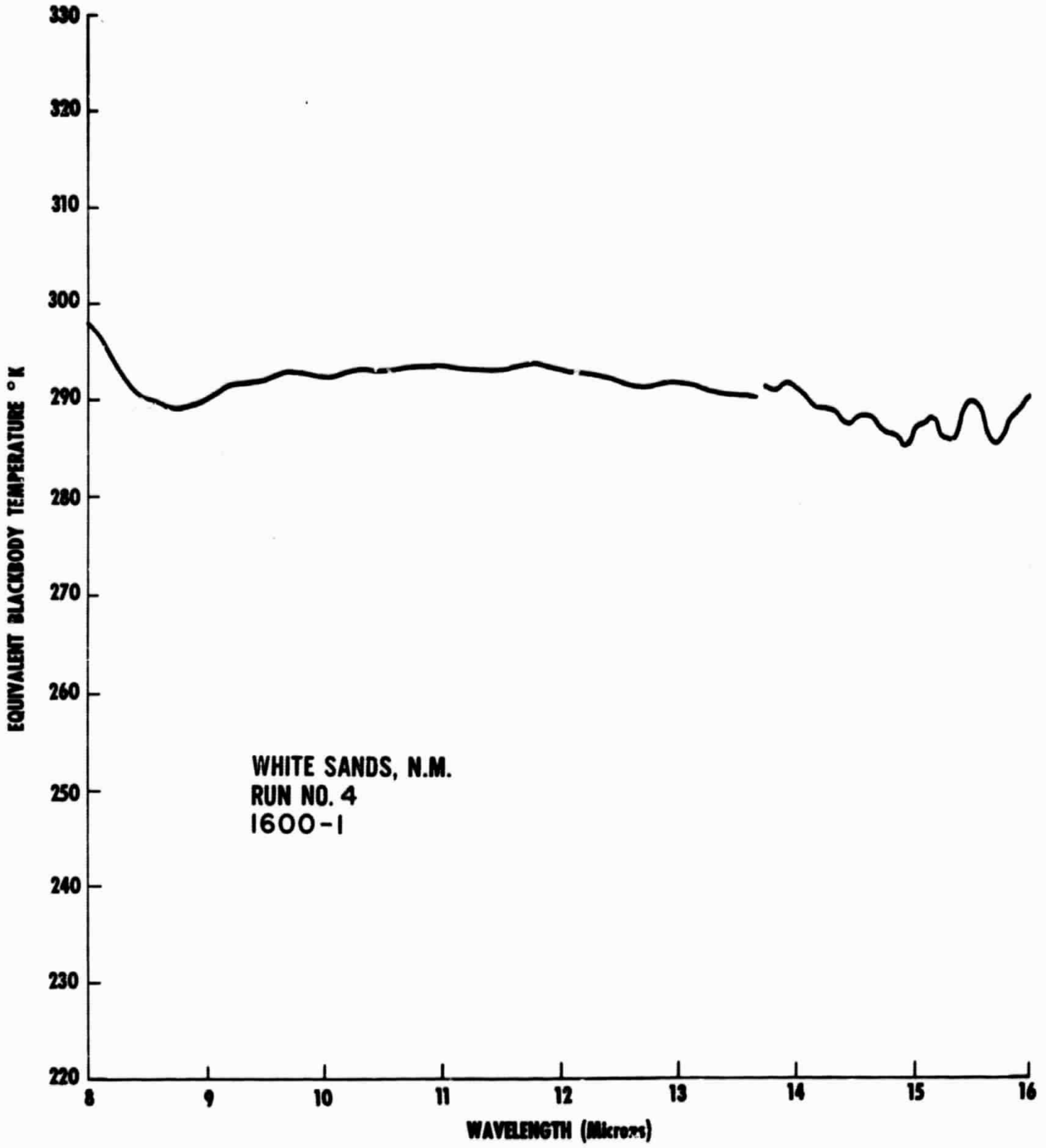
15
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 4
1559-2


330
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230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
8
9
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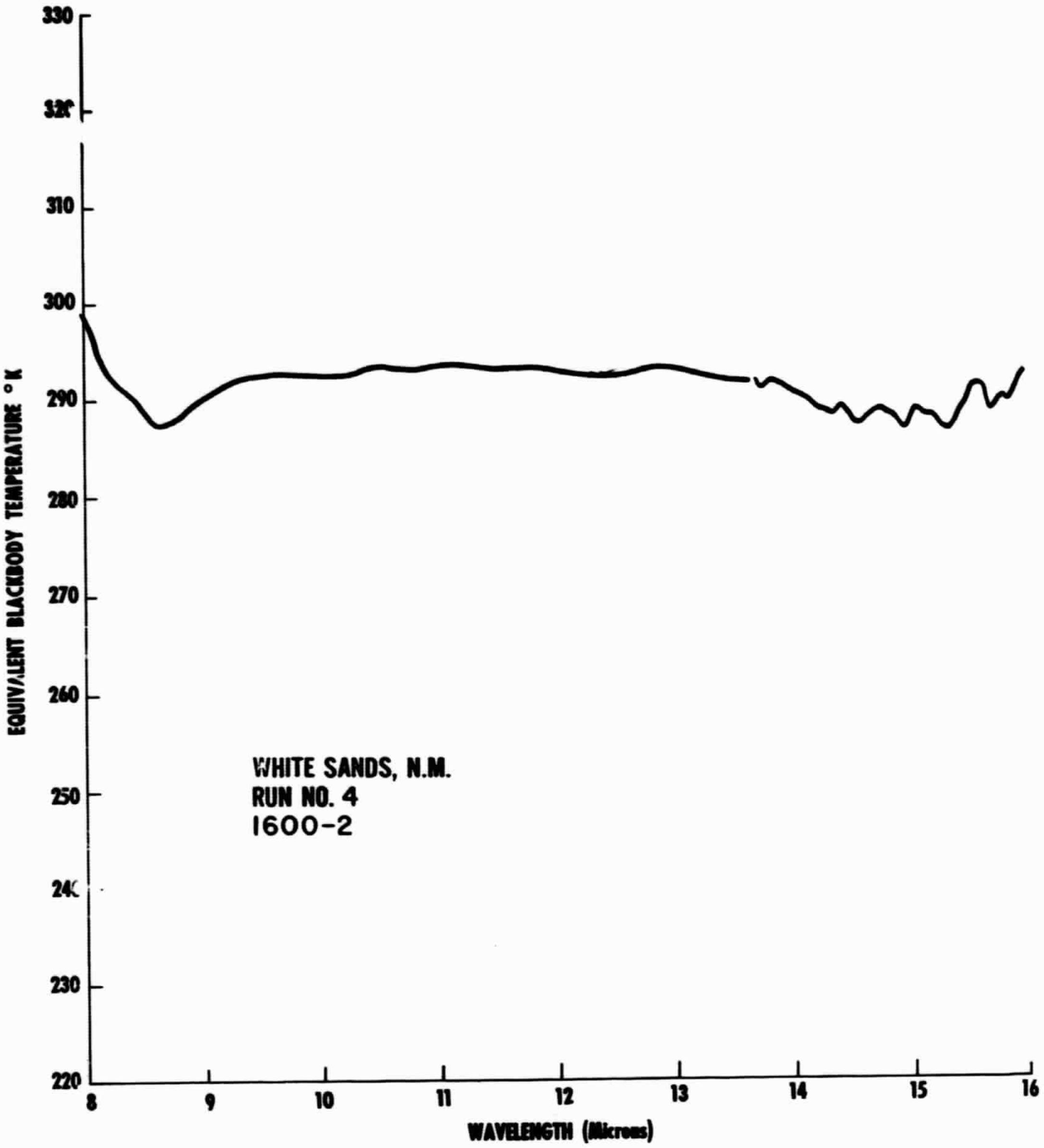
11
12
13
14
15
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 4
1600-1


330
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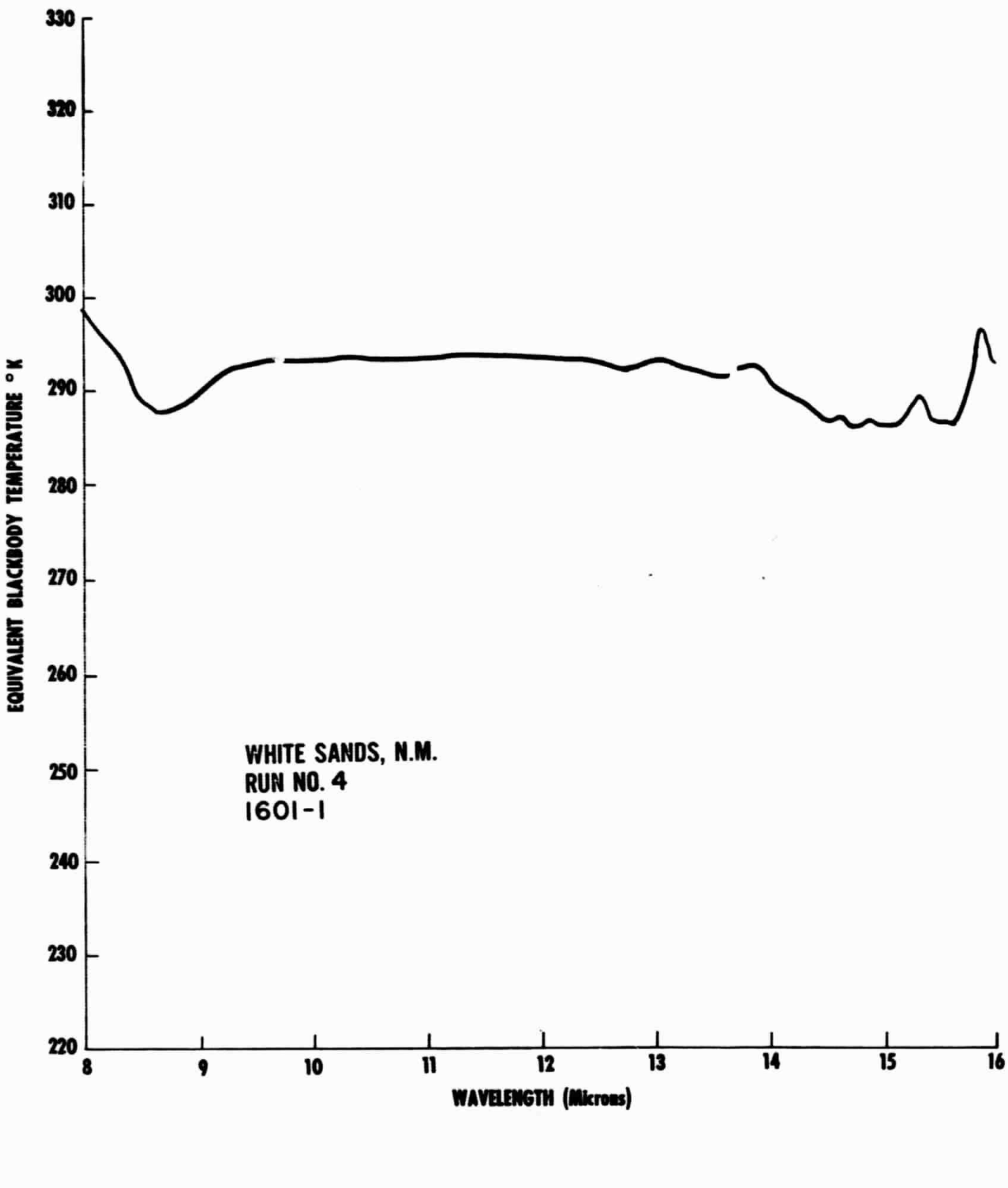
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 4
1600-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 4
1601-1
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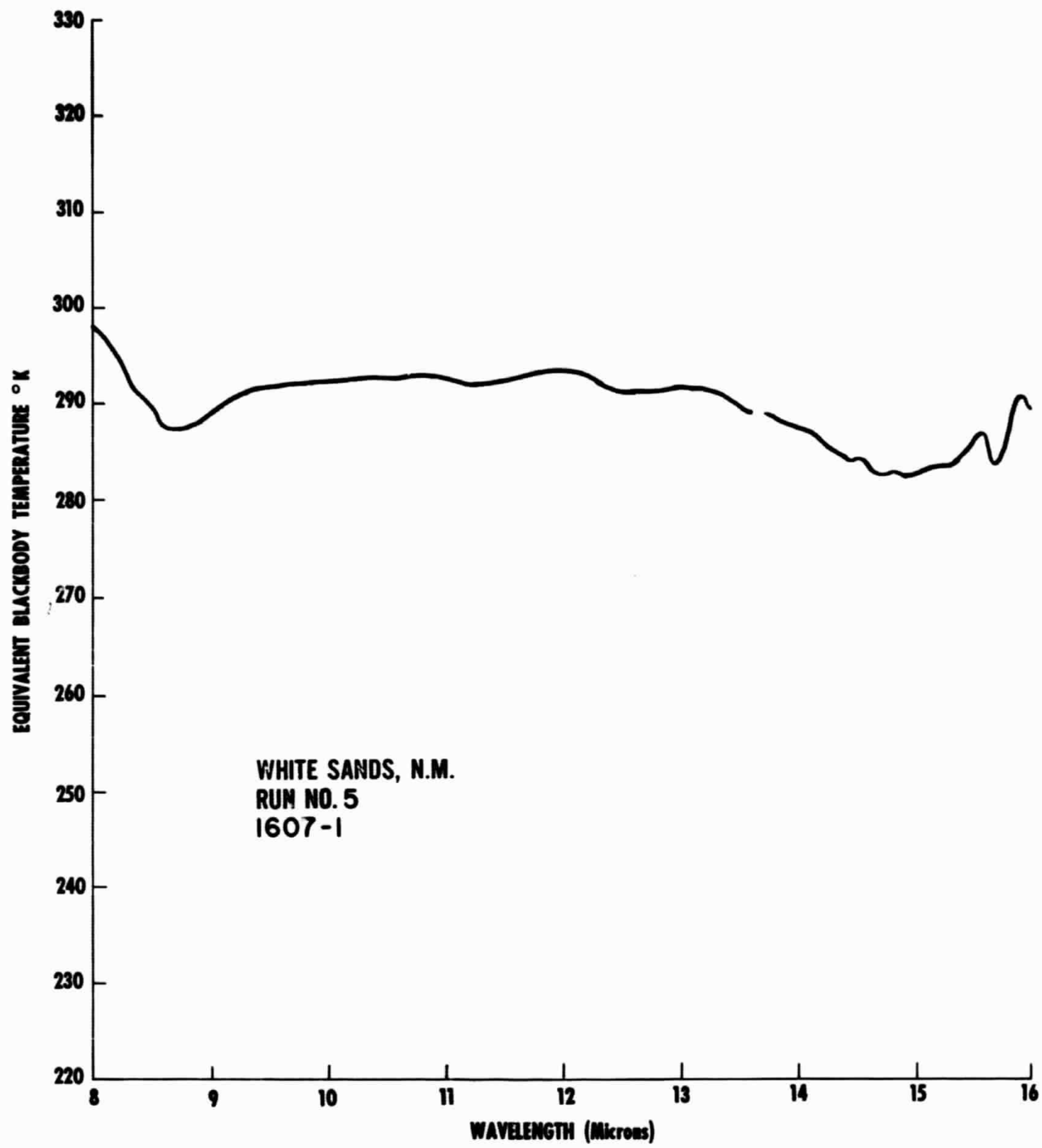
16
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 5
1607-1
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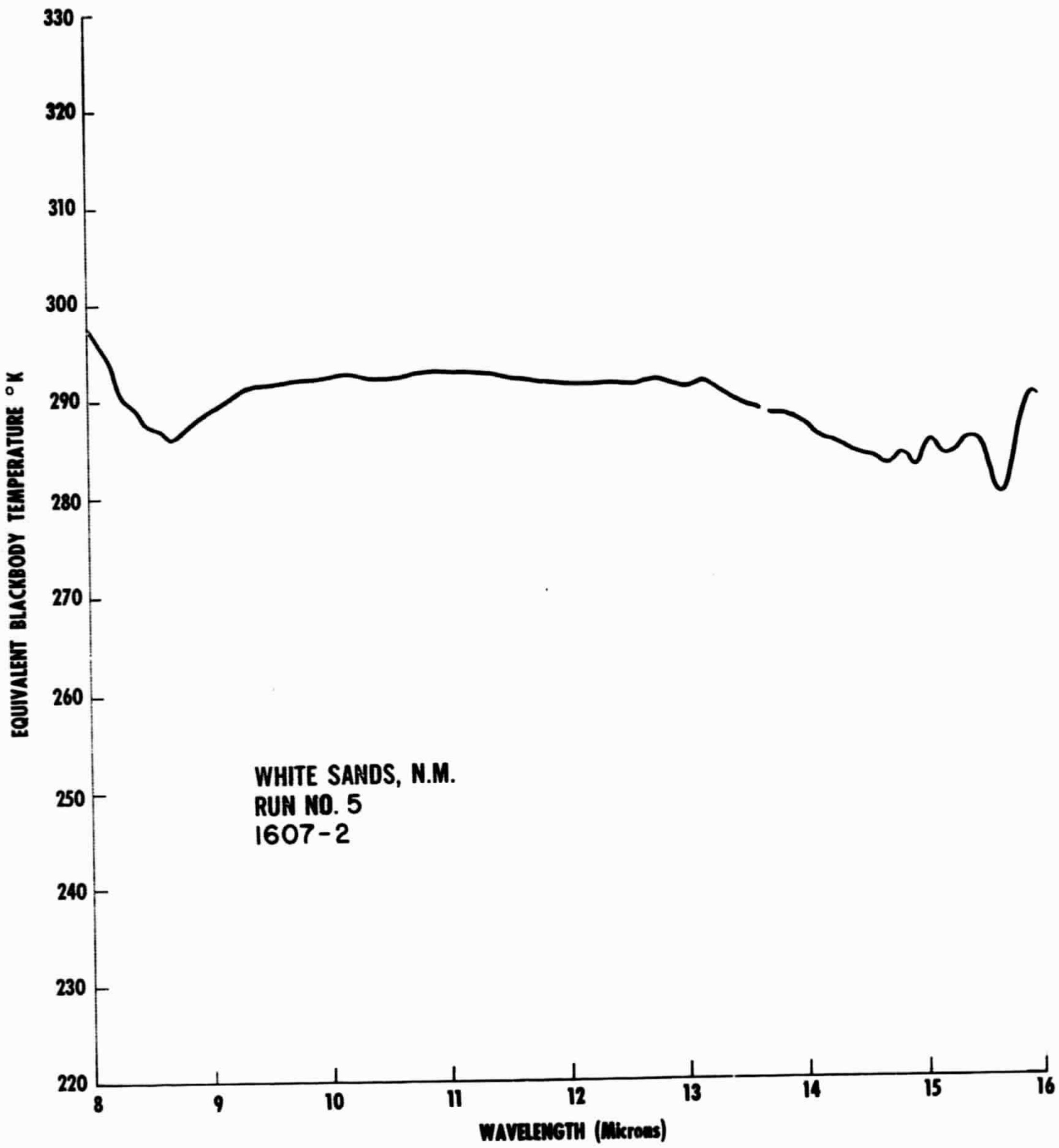
WAVELENGTH (Microns)



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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 5
1607-2
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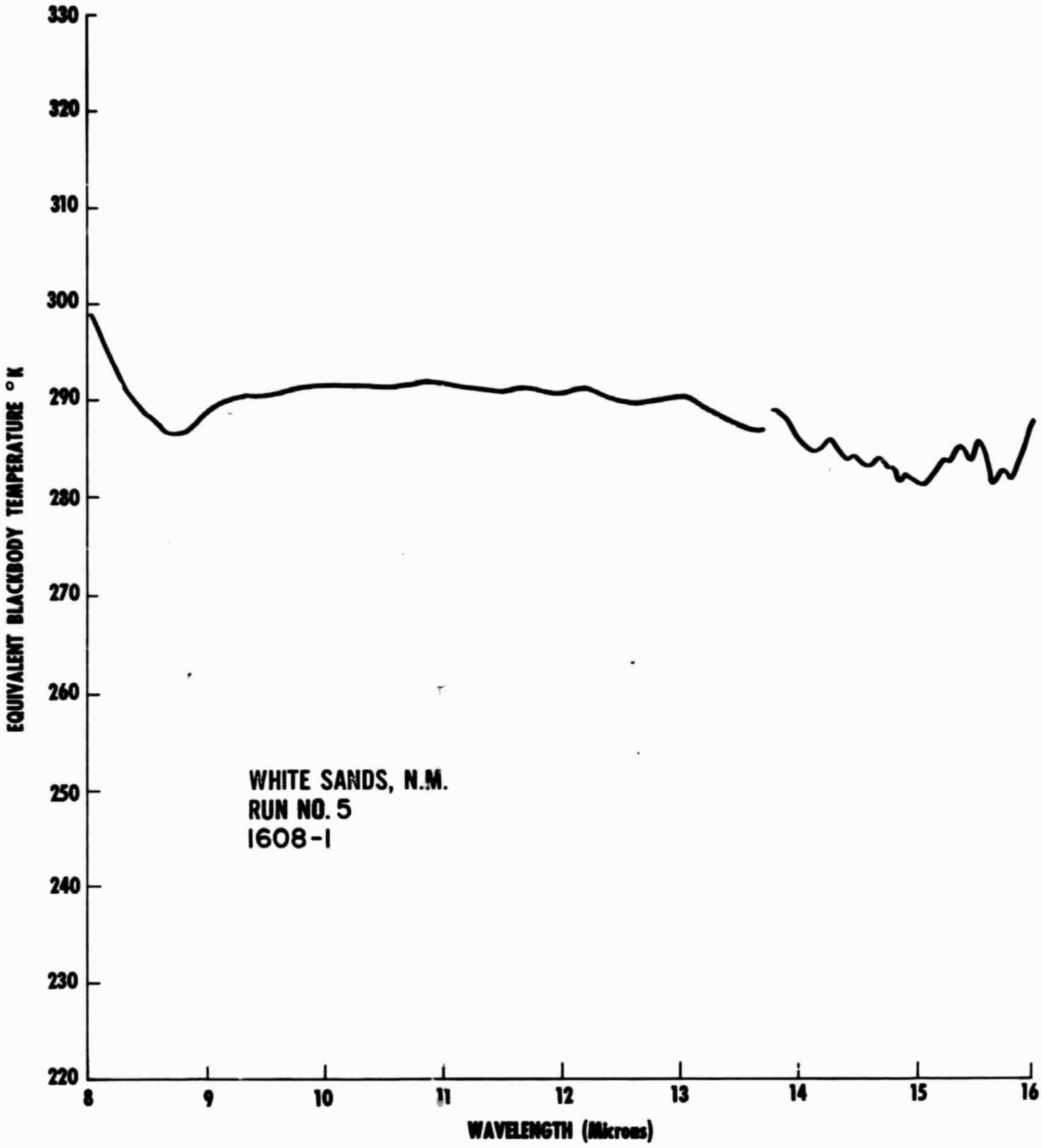
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 5
1608-1
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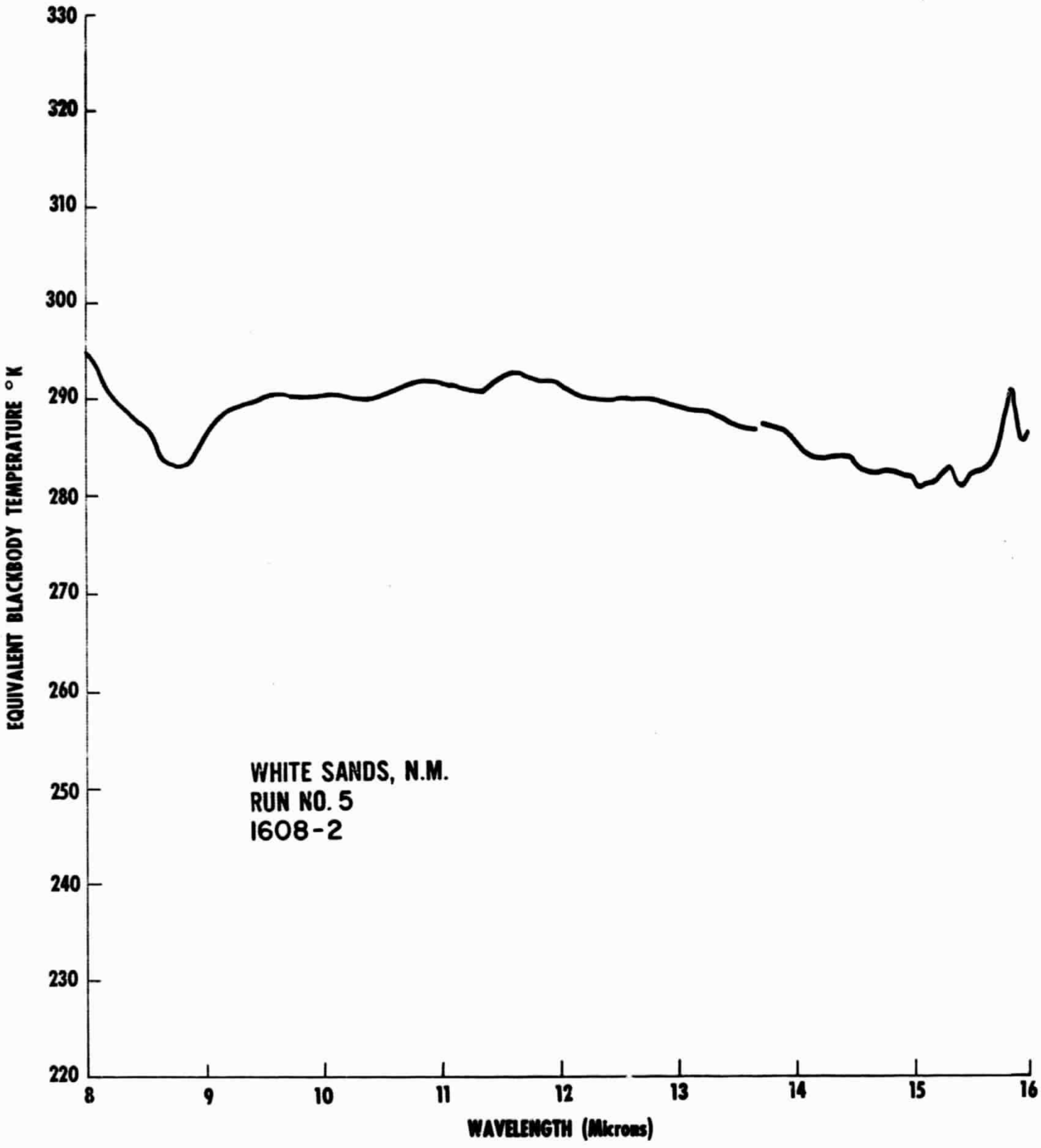
WAVELENGTH (Microns)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RUN NO. 5
1608-2
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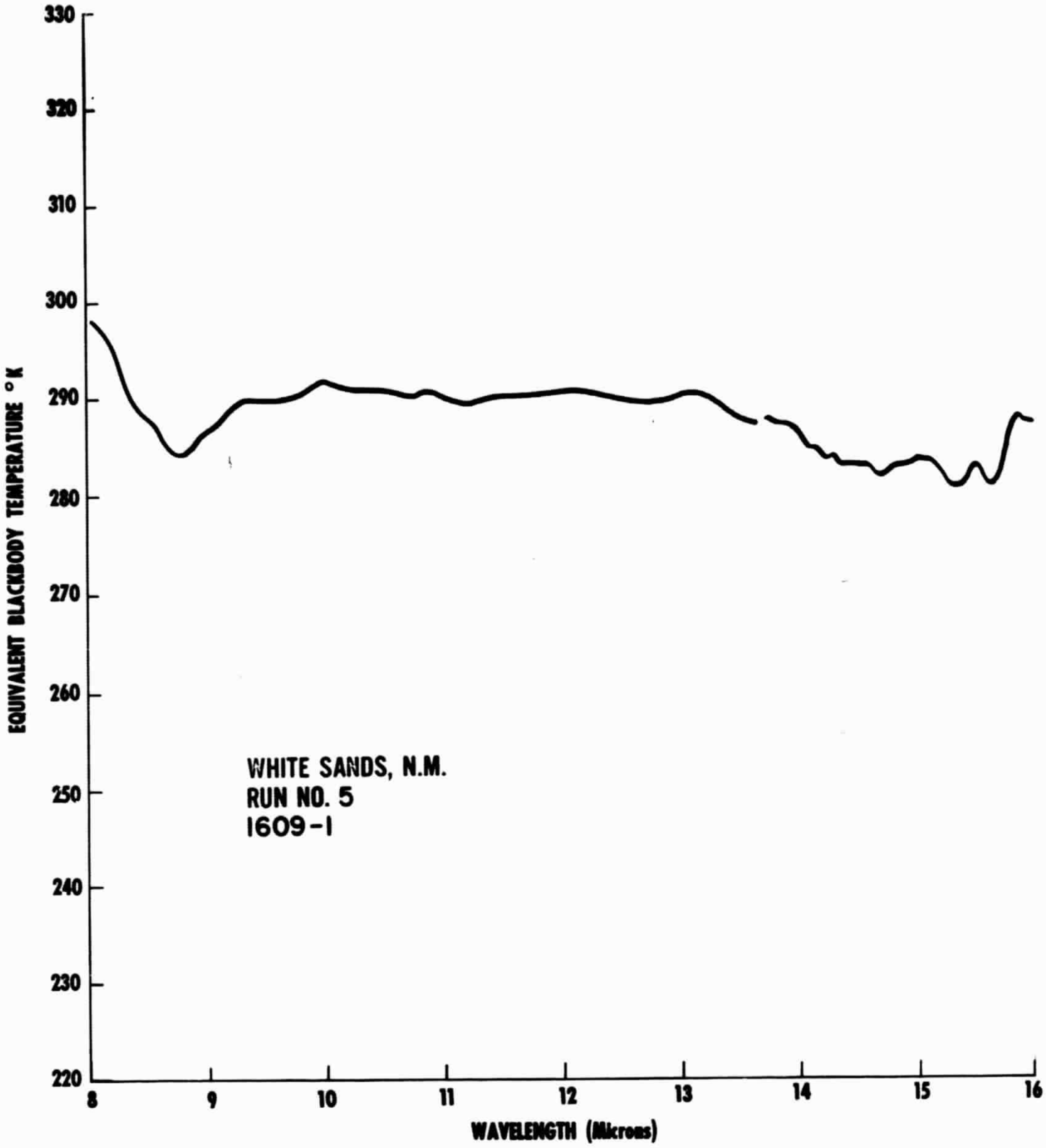
WAVELENGTH (Microns)



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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 5
1609-1
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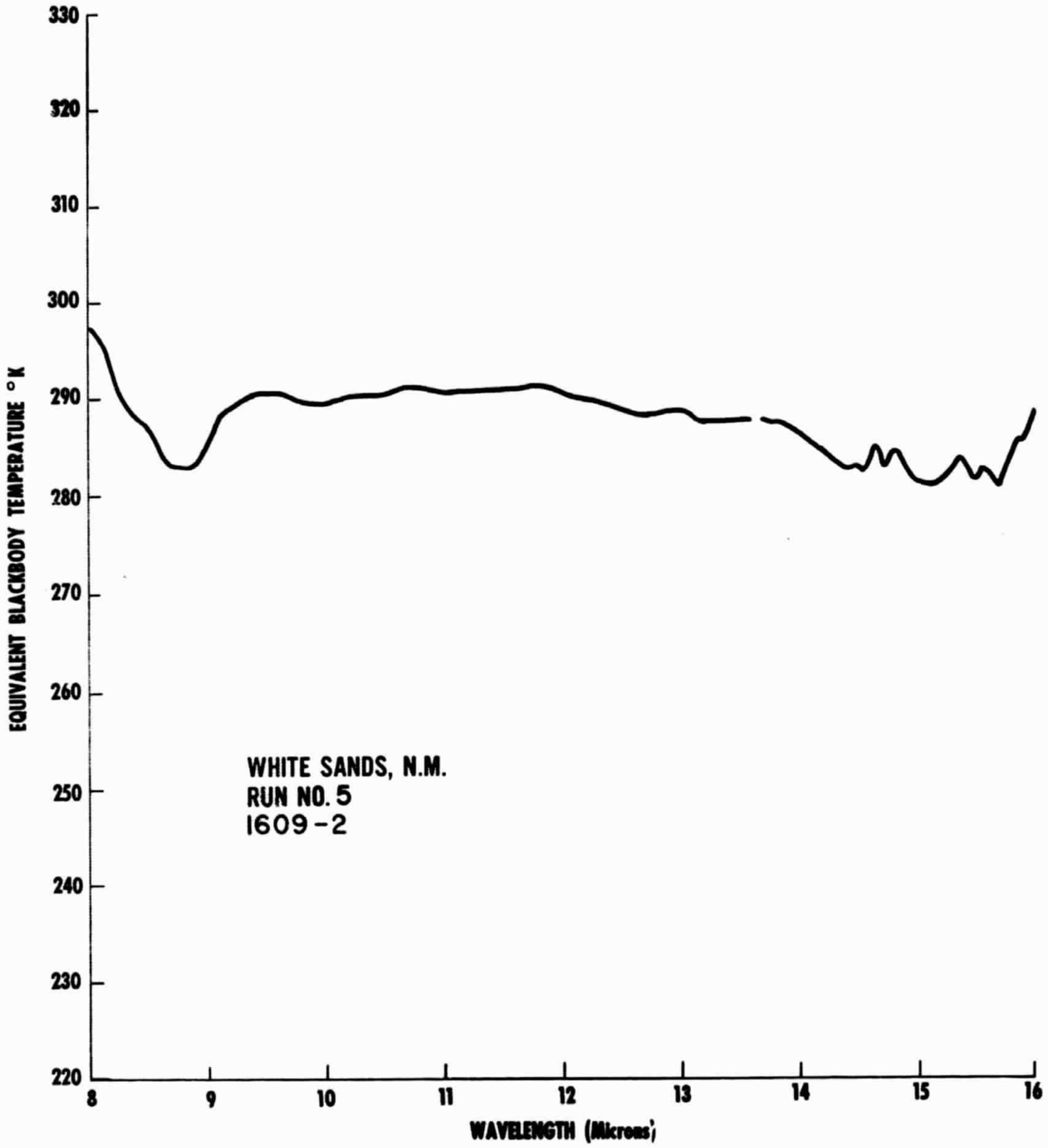
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 5
1609-2
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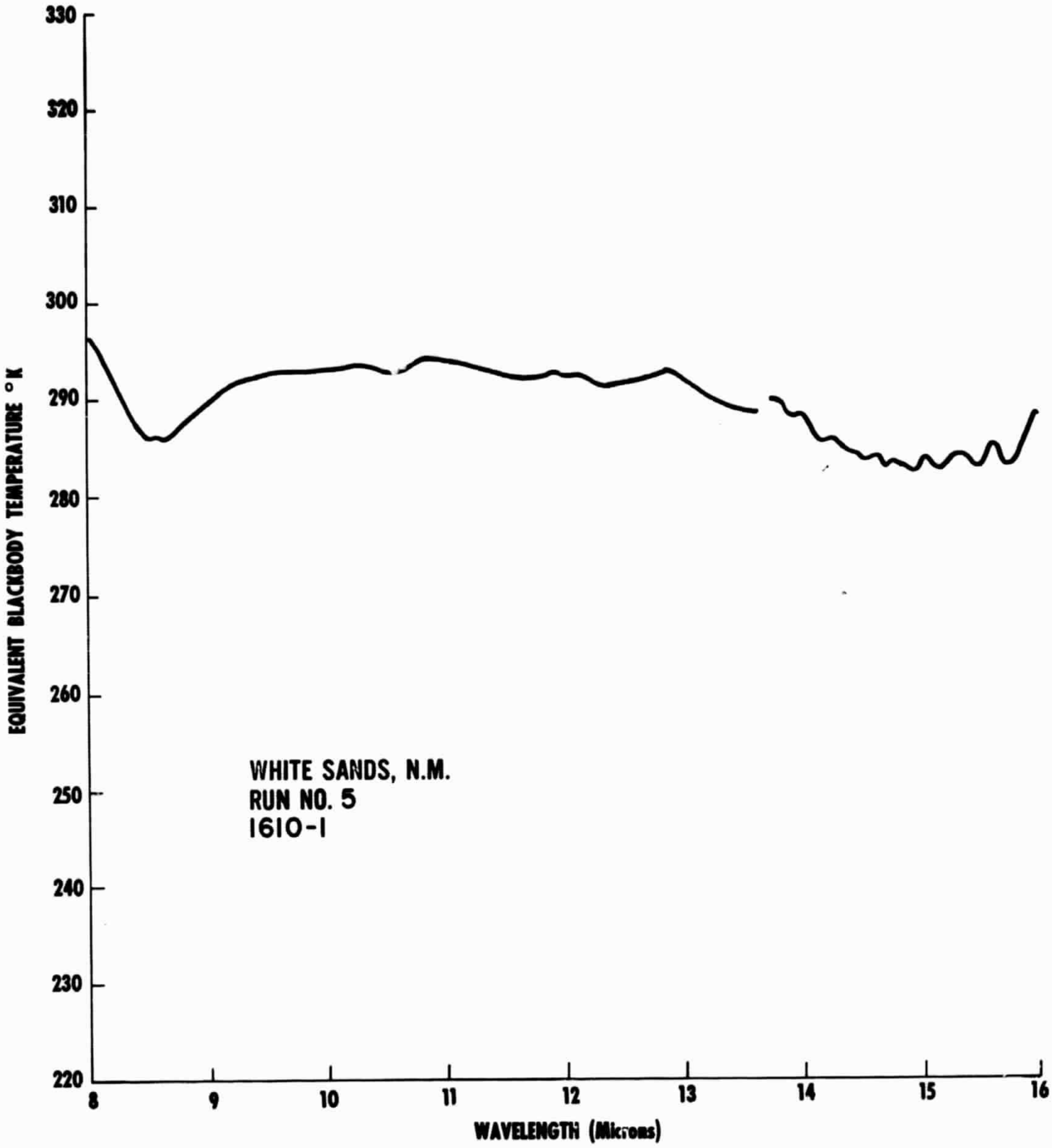
WAVELENGTH (Microns)



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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 5
1610-1
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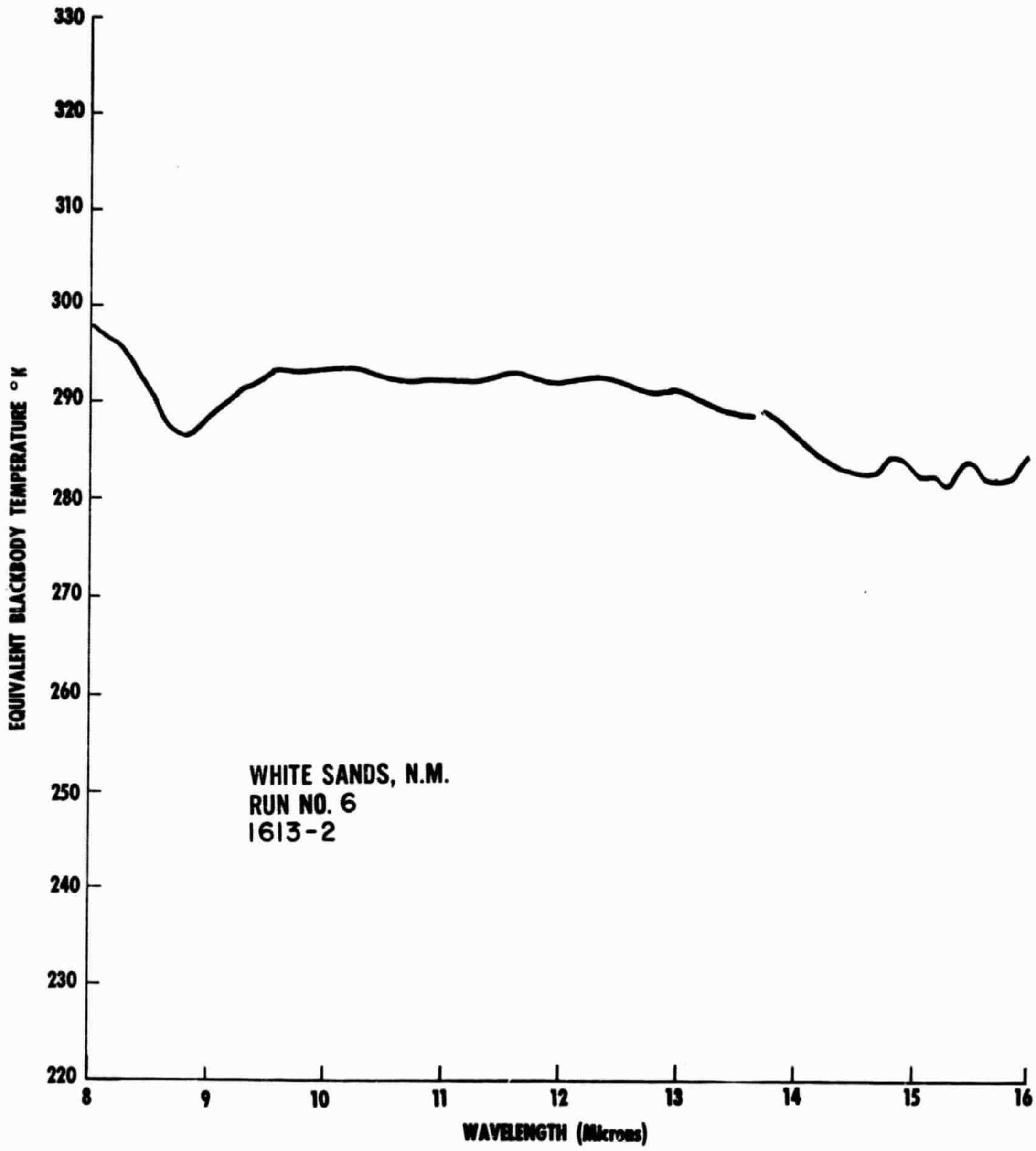
WAVELENGTH (Microns)



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EQUIVALENT BLACKBODY TEMPERATURE °K
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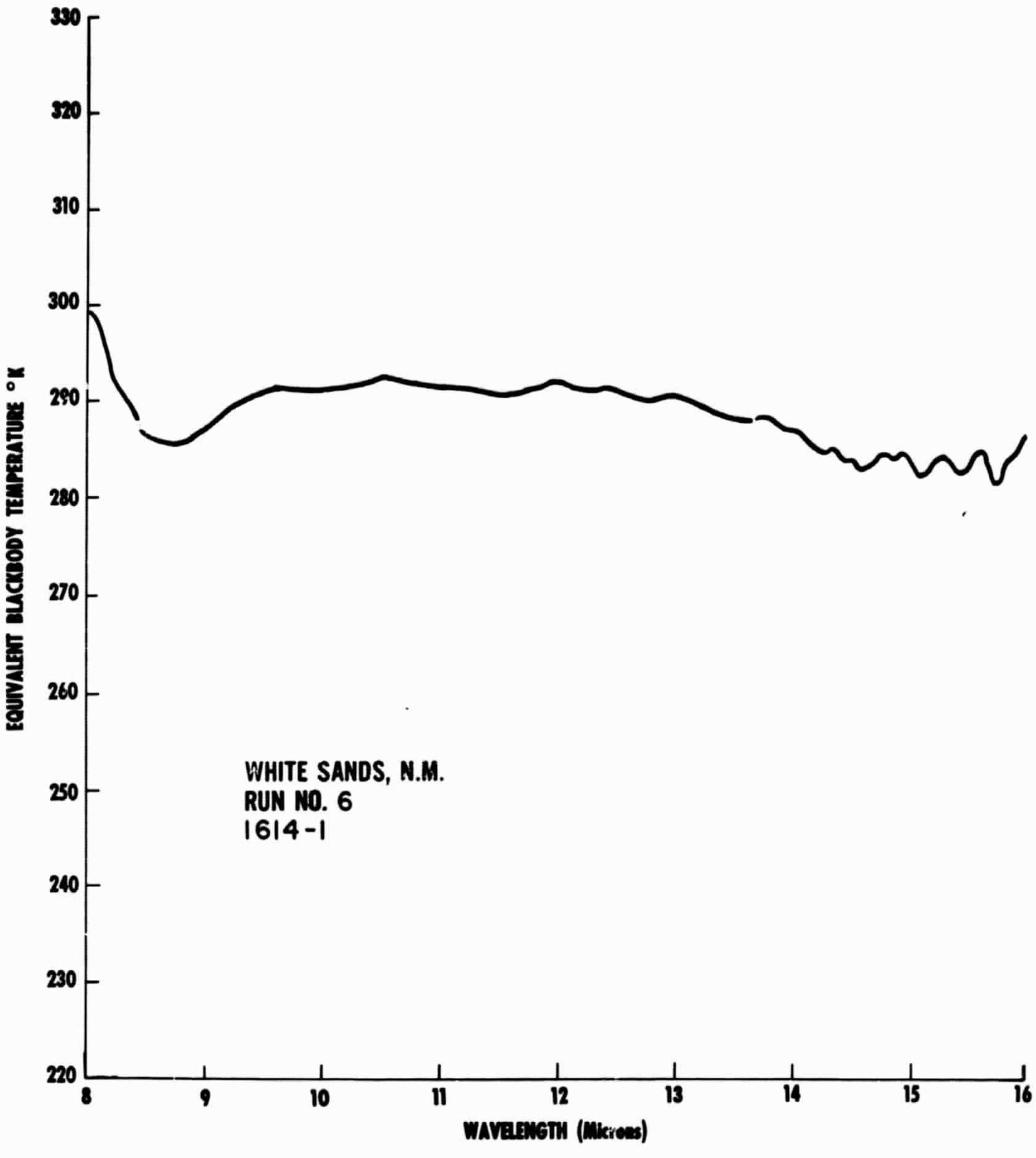
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 6
1613-2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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 6
1614-1
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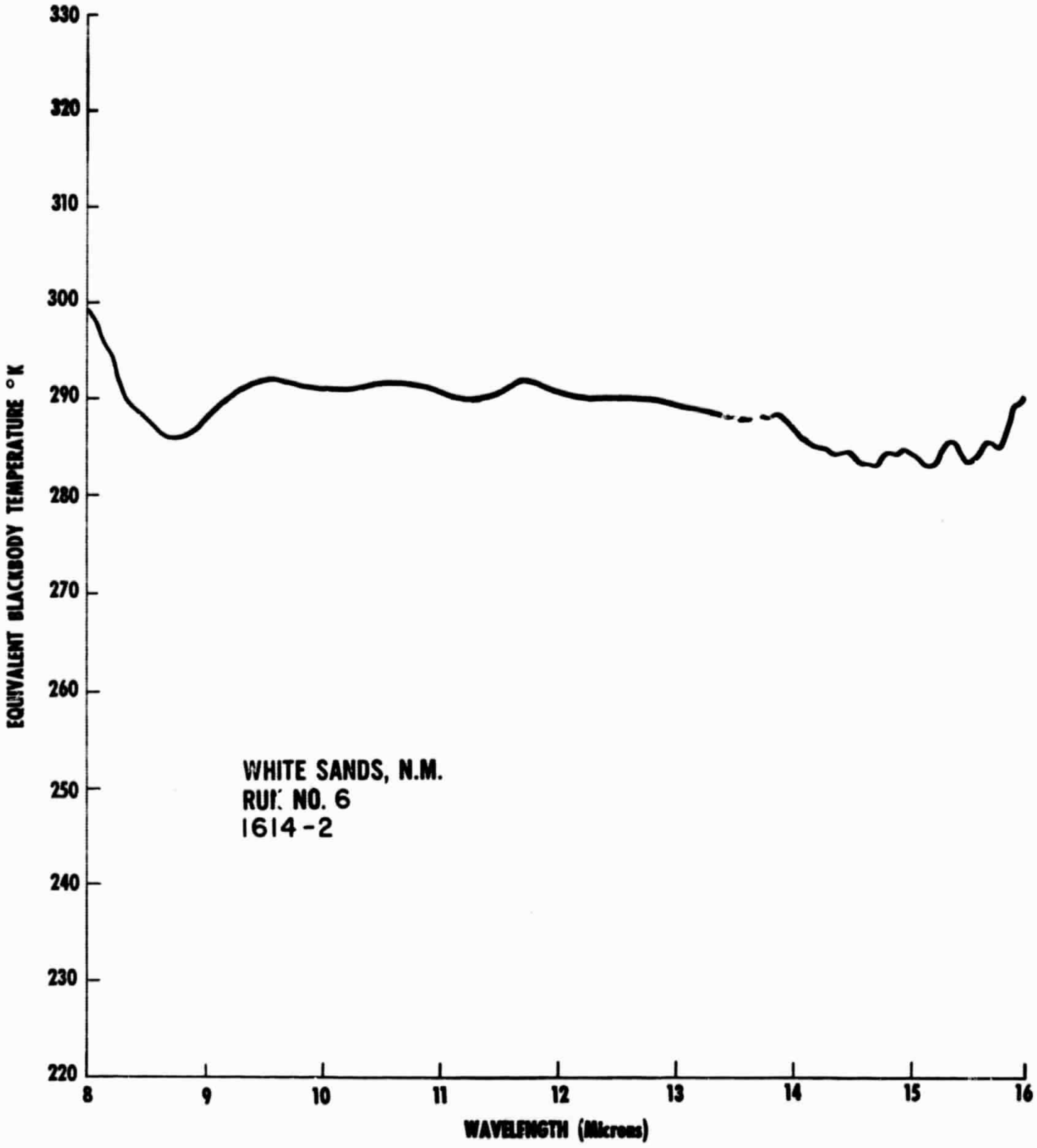
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 6
1614-2
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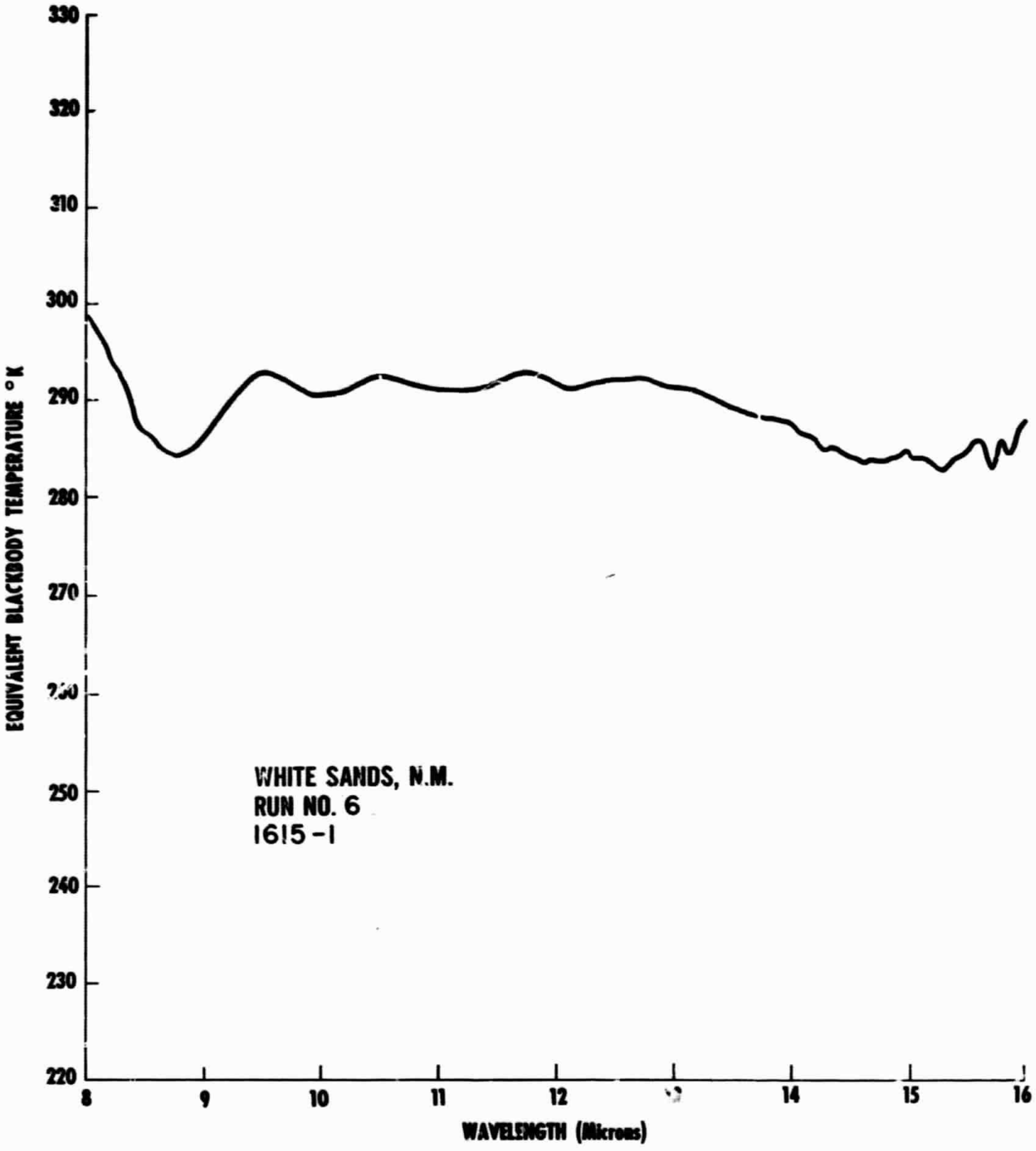
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 6
1615 -1
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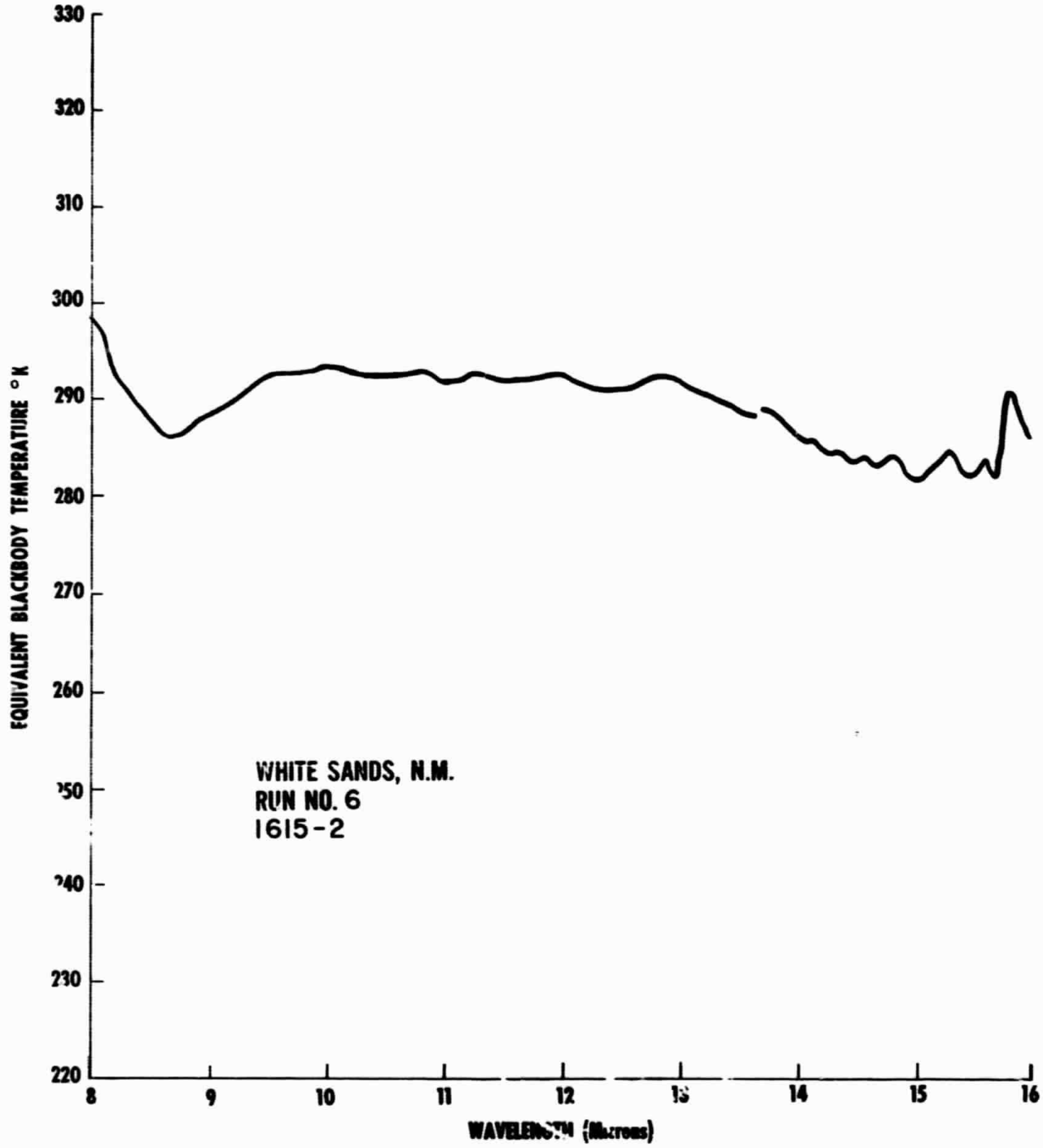
WAVELENGTH (Microns)


EQUIVALENT BLACKBODY TEMPERATURE °K
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WHITE SANDS, N.M.
RUN NO. 6
1615-2
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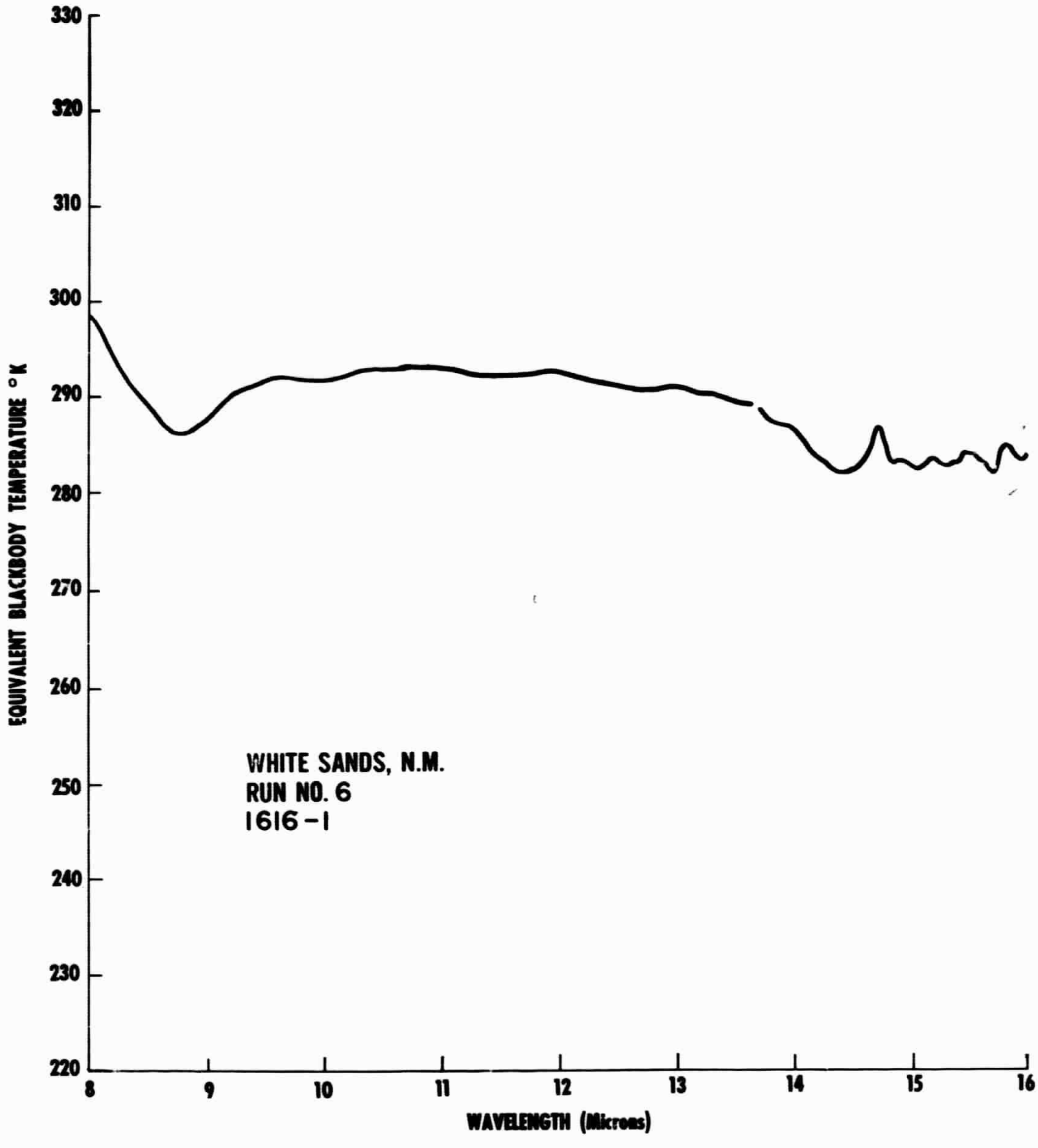
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
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RUN NO. 6
1616-1
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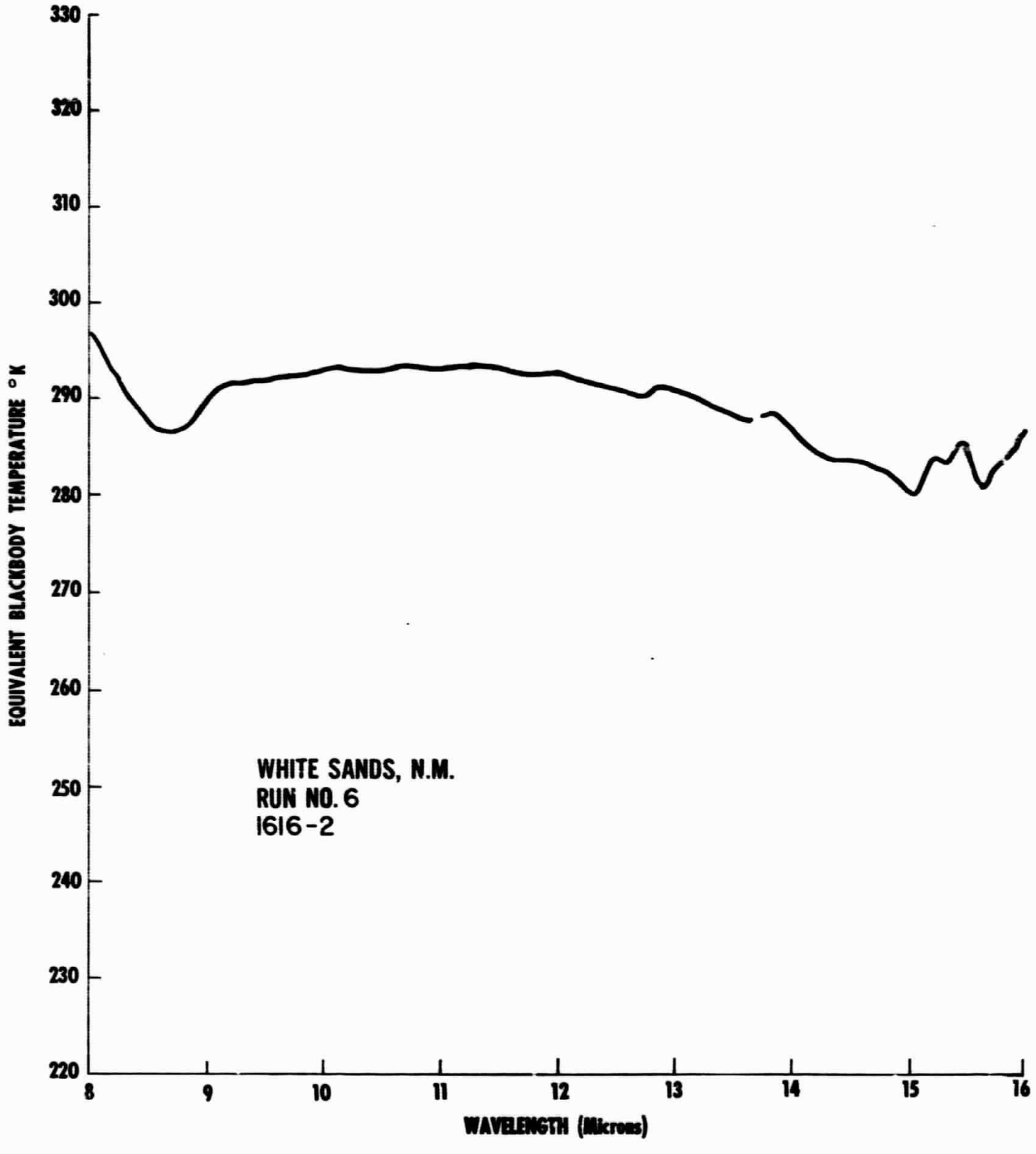
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
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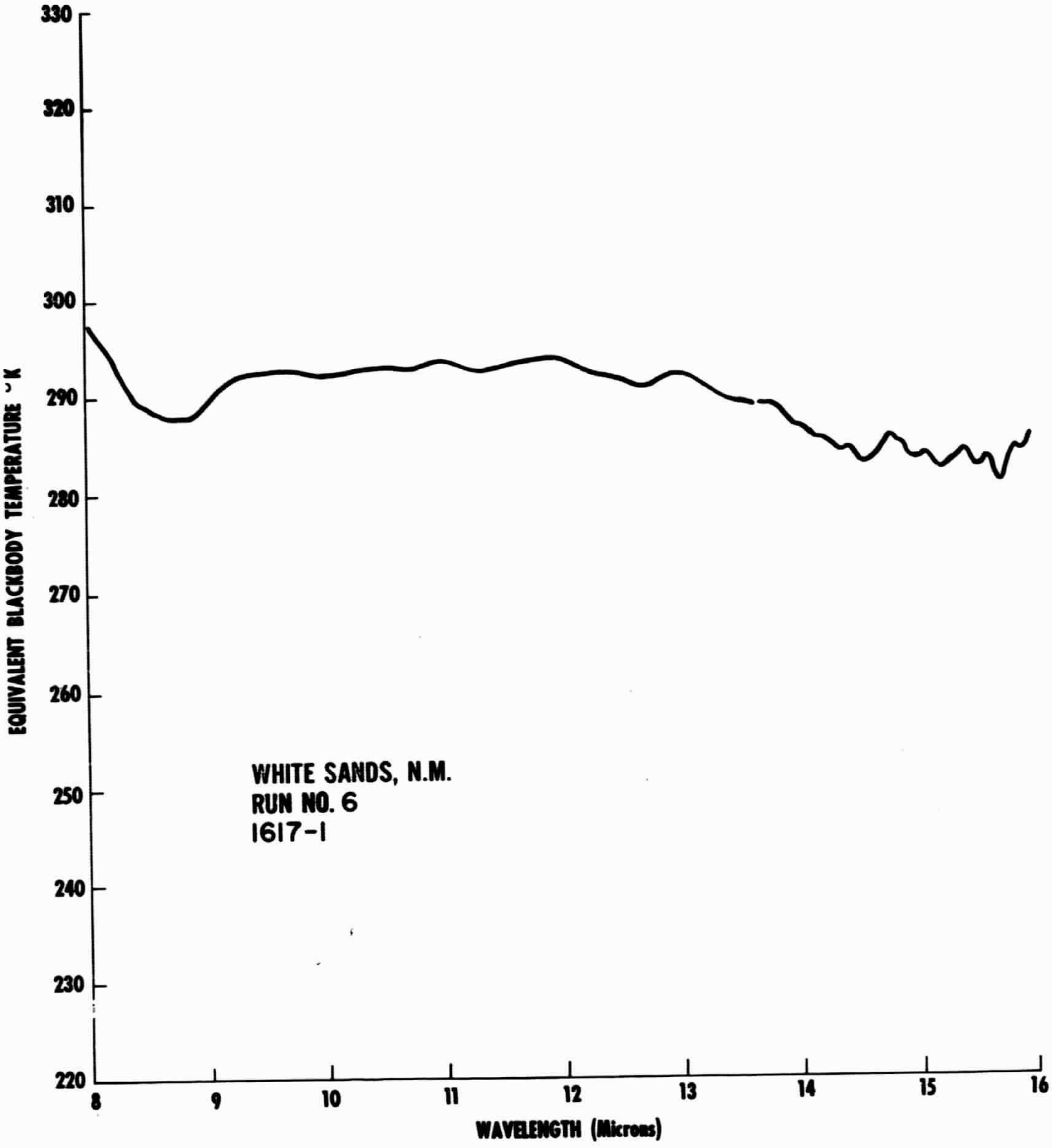
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 6
1616-2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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 6
1617-1
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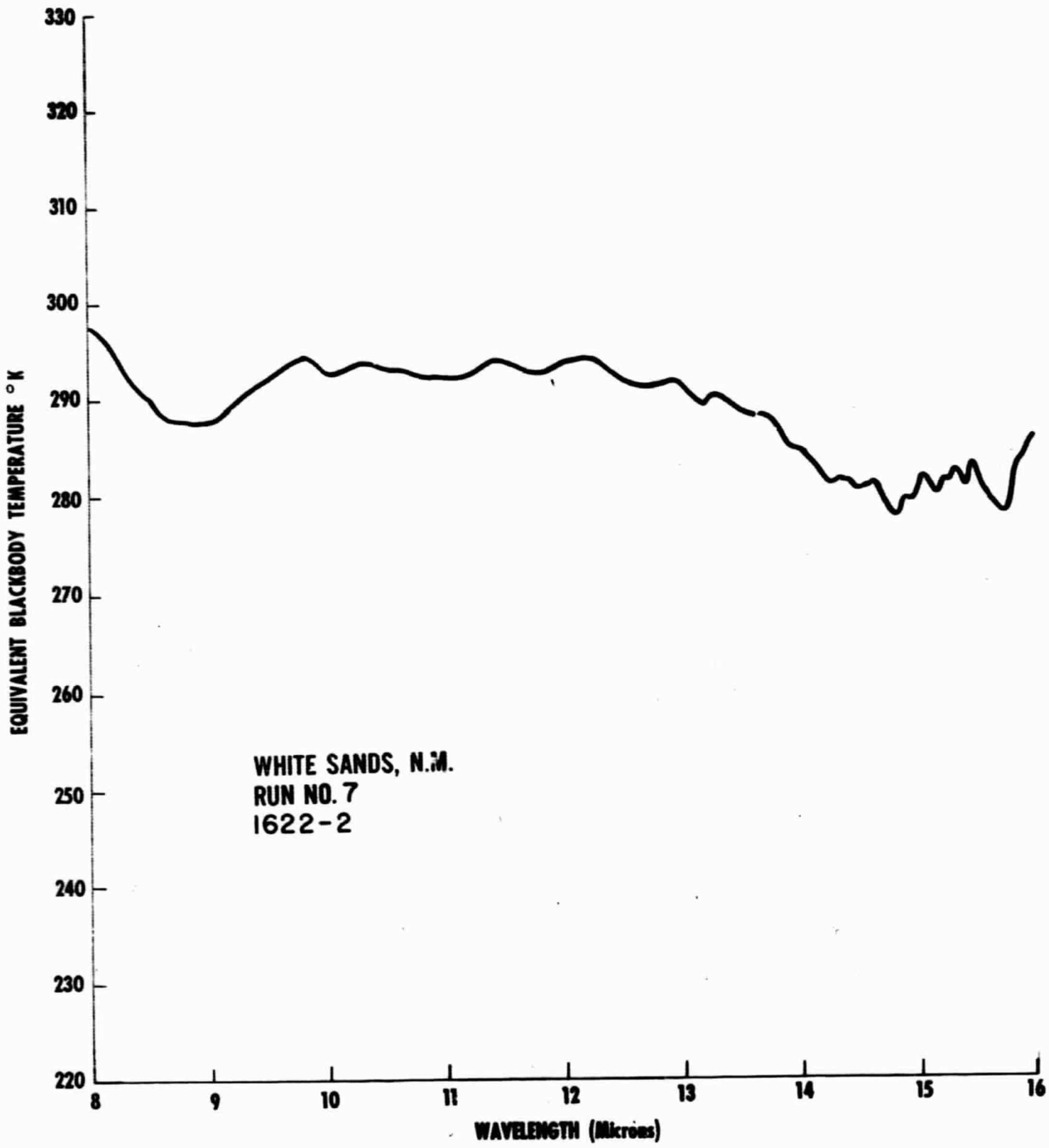
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 7
1622-2
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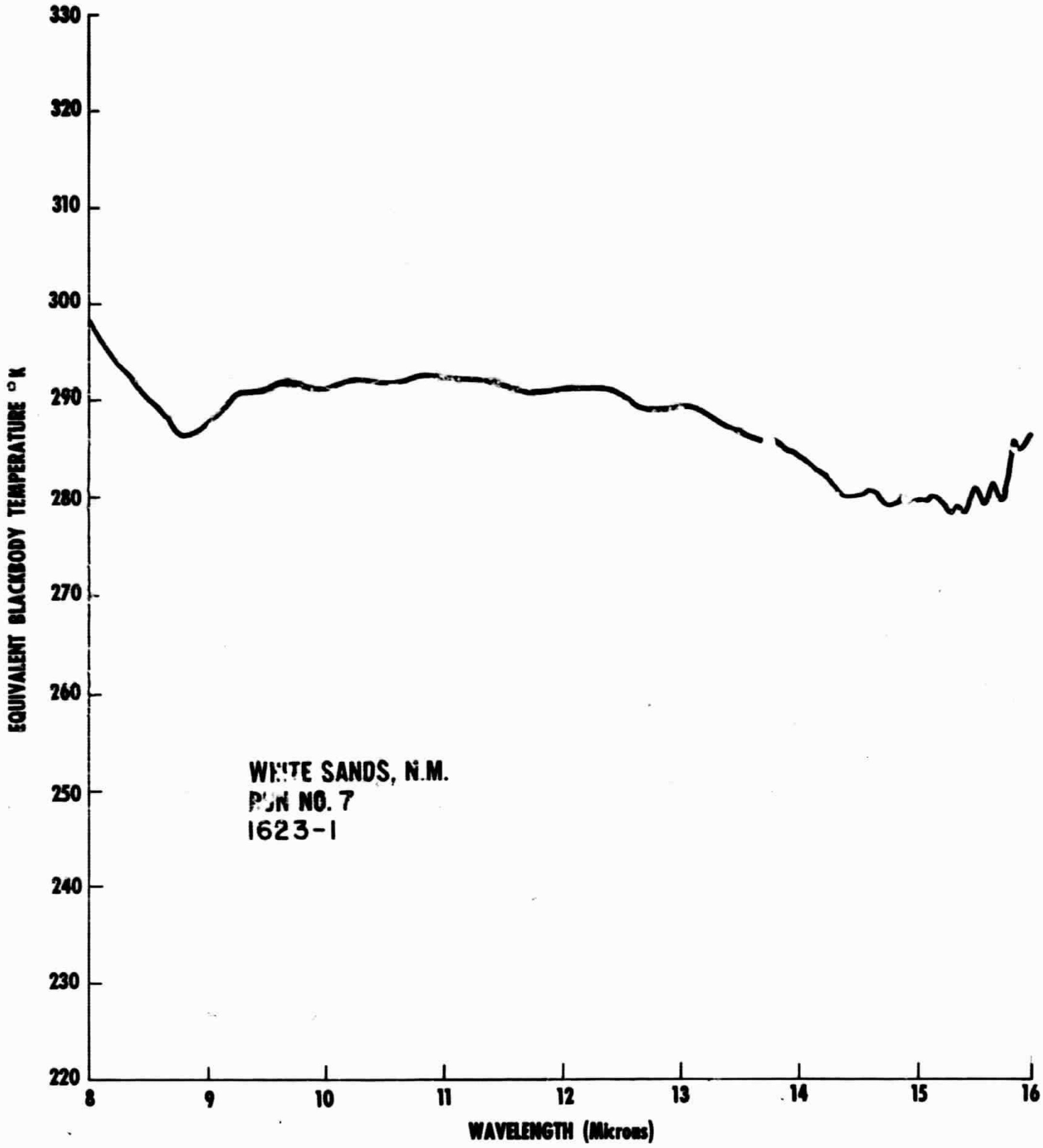
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 7
1623-1
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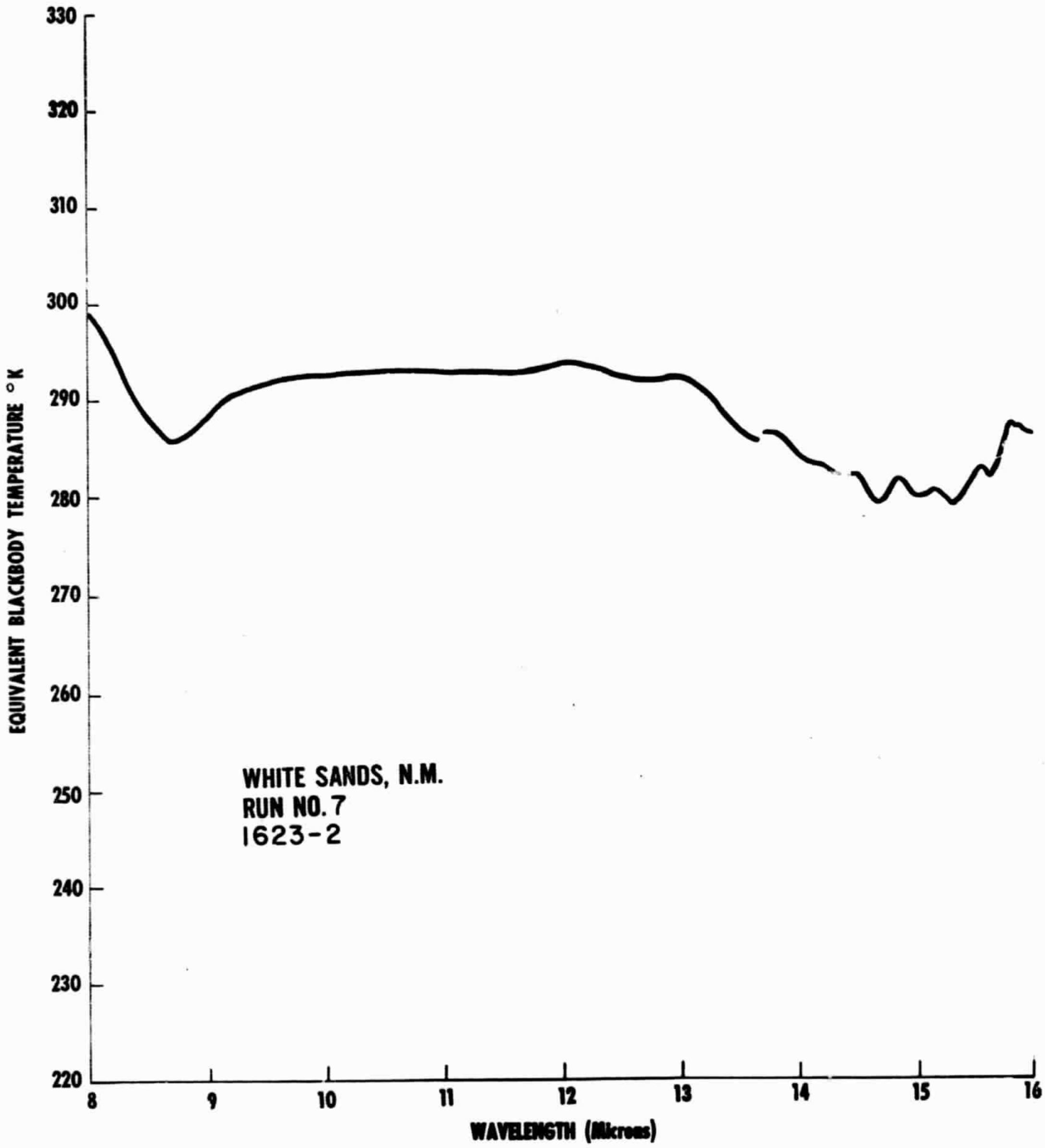
WAVELENGTH (Mikrons)



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EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 7
1623-2
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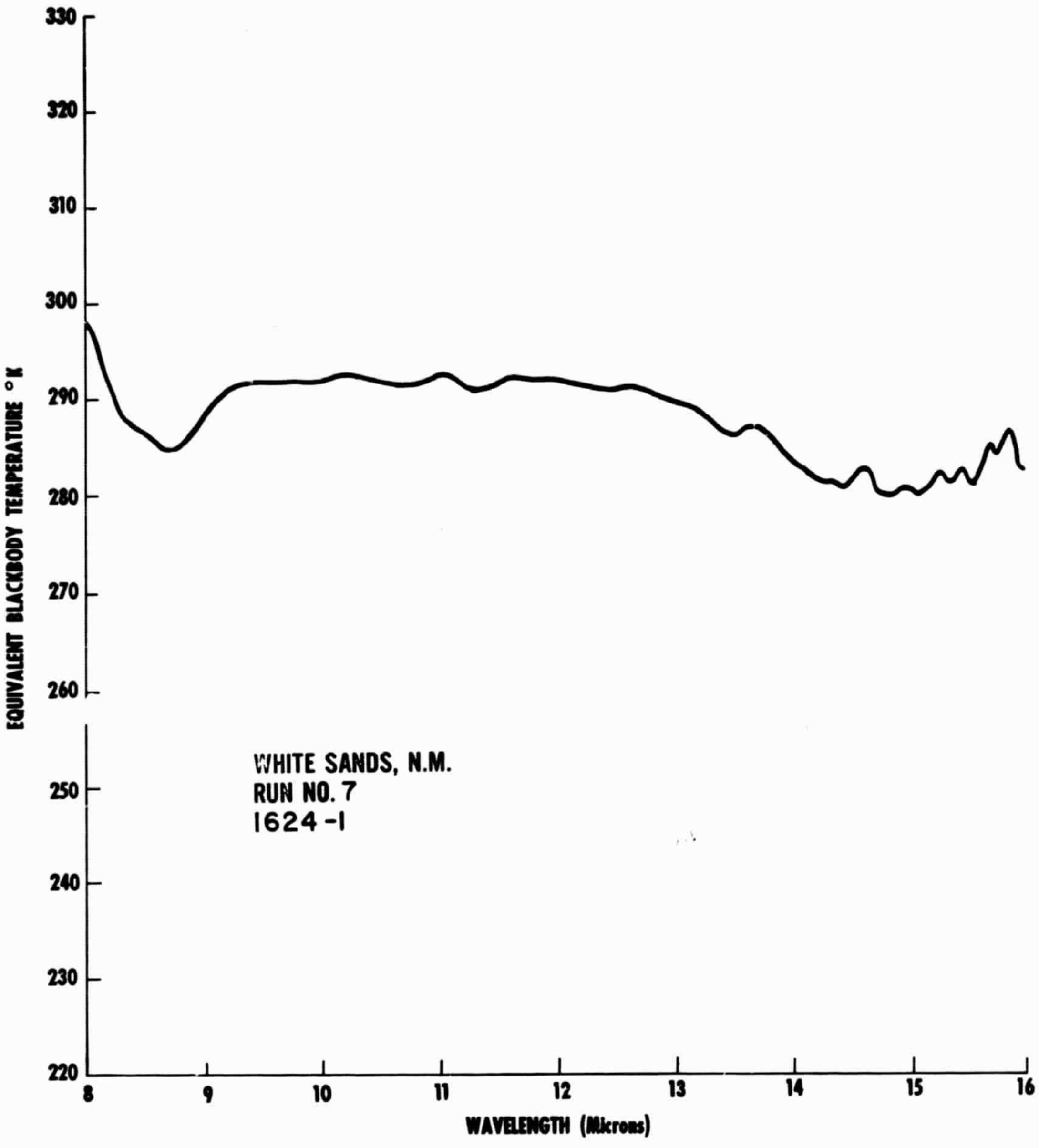
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 7
1624 -1
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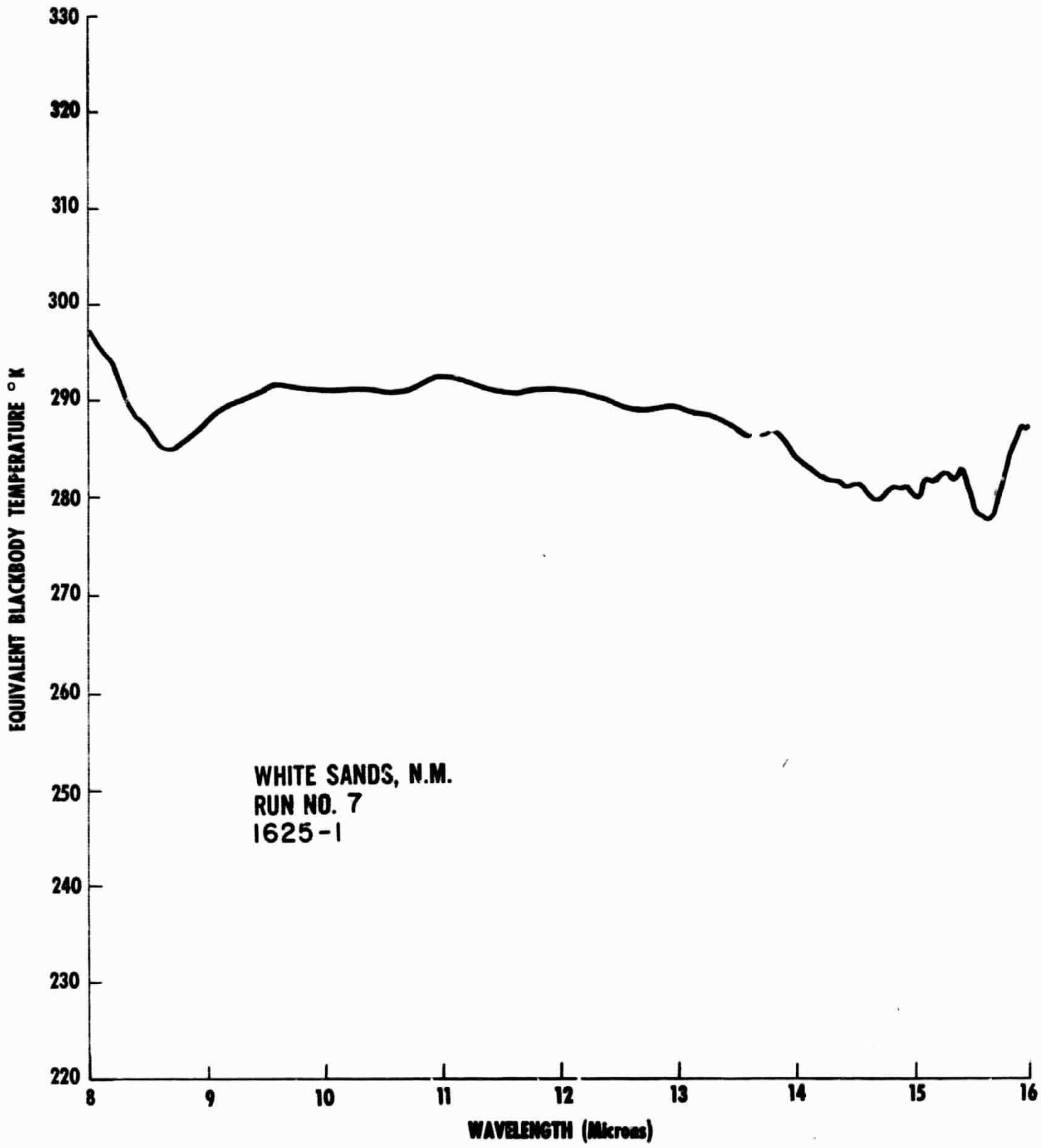
WAVELENGTH (Microns)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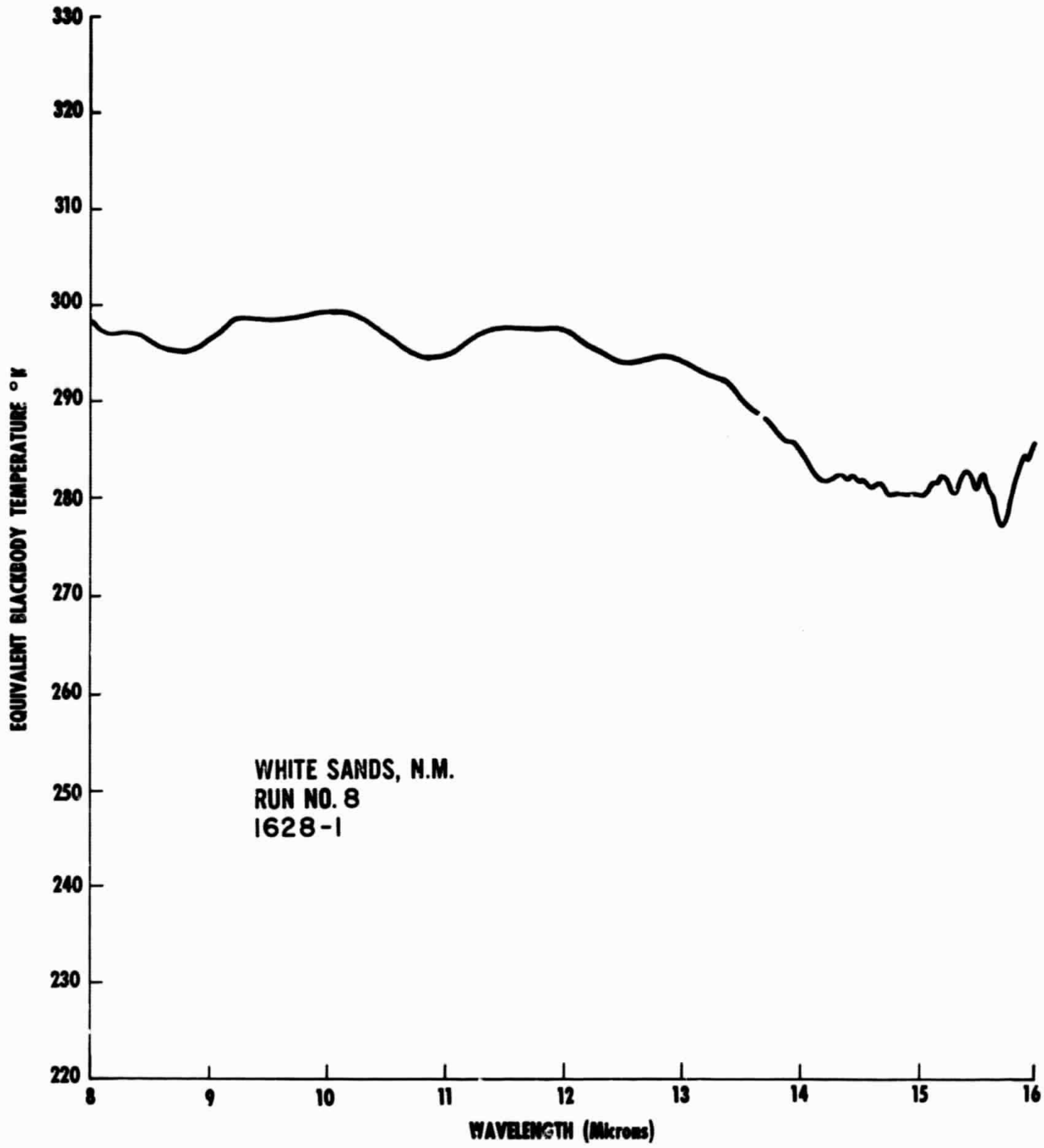
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 7
1625-1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EQUIVALENT BLACKBODY TEMPERATURE °K
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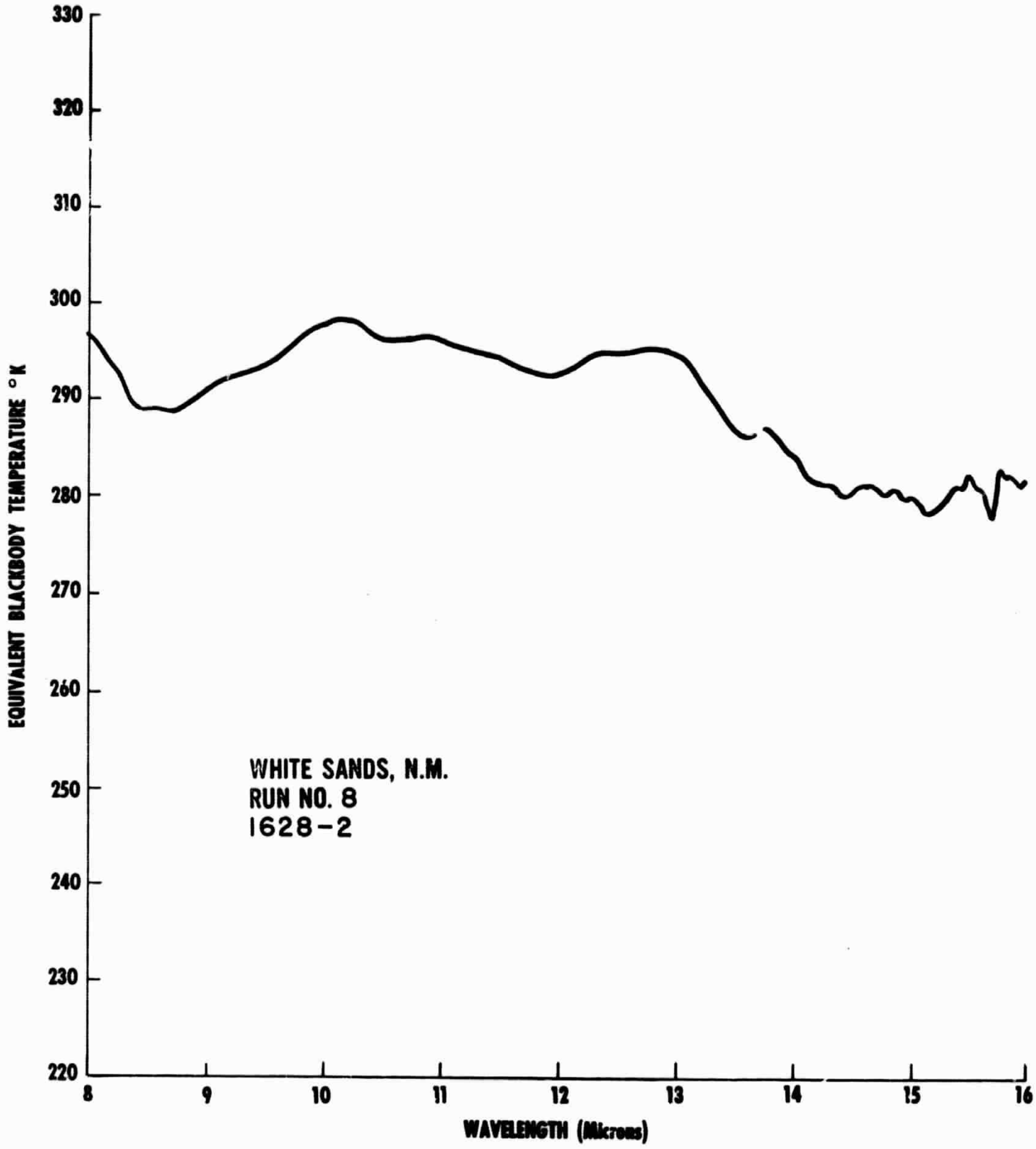
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 8
1628-1



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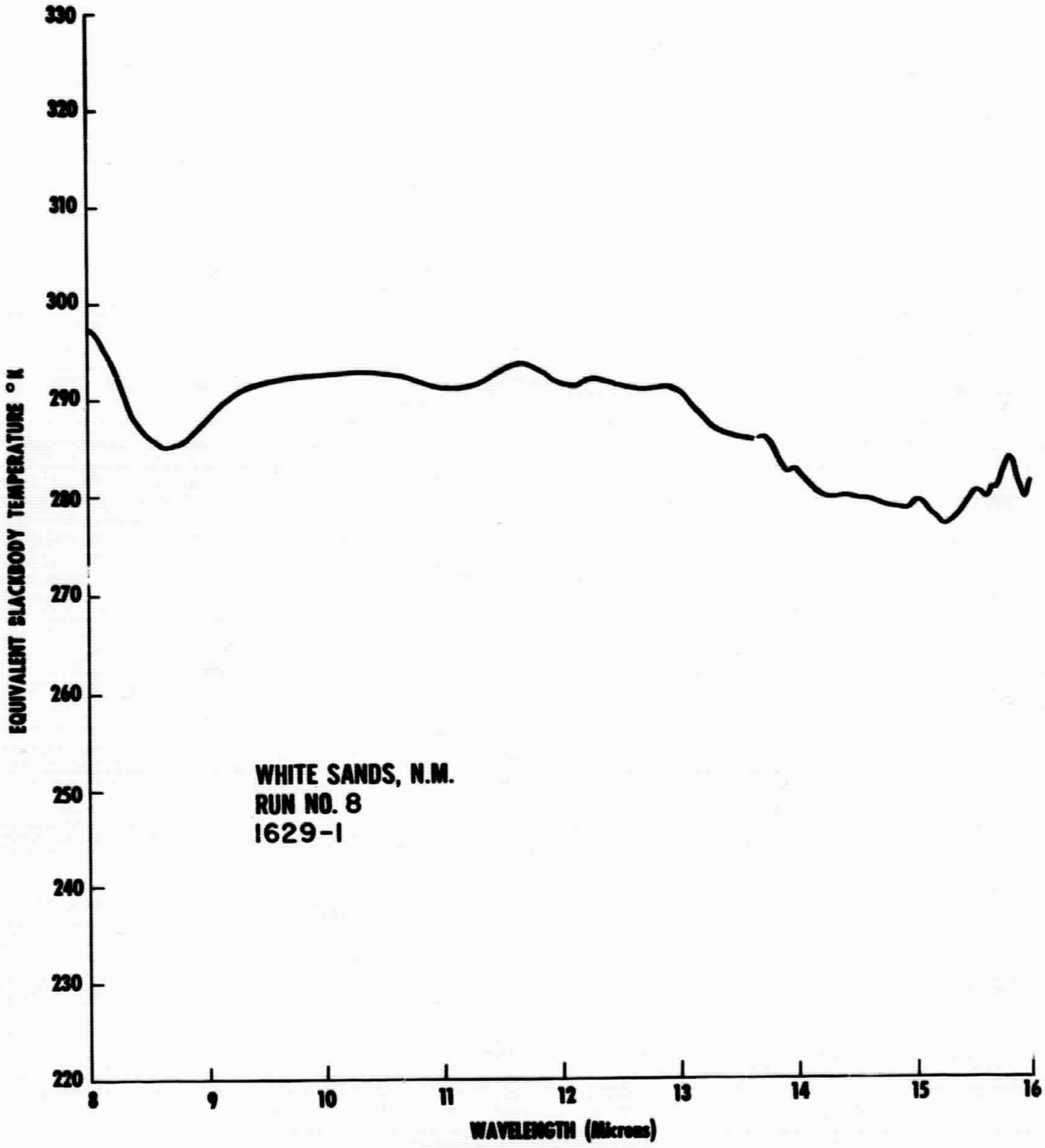
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 8
1628-2



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EQUIVALENT BLACKBODY TEMPERATURE °K
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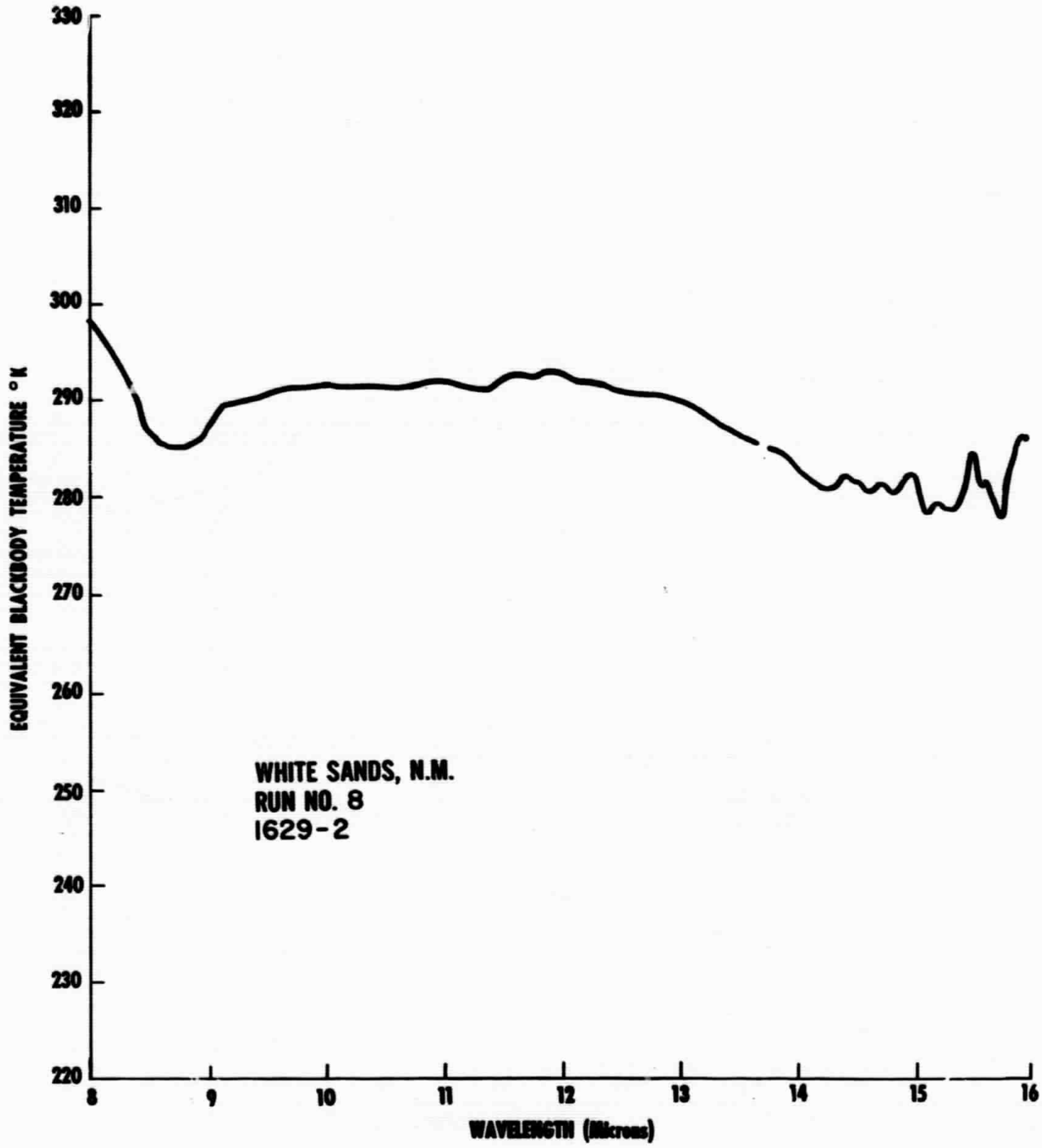
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 8
1629-1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EQUIVALENT BLACKBODY TEMPERATURE °K
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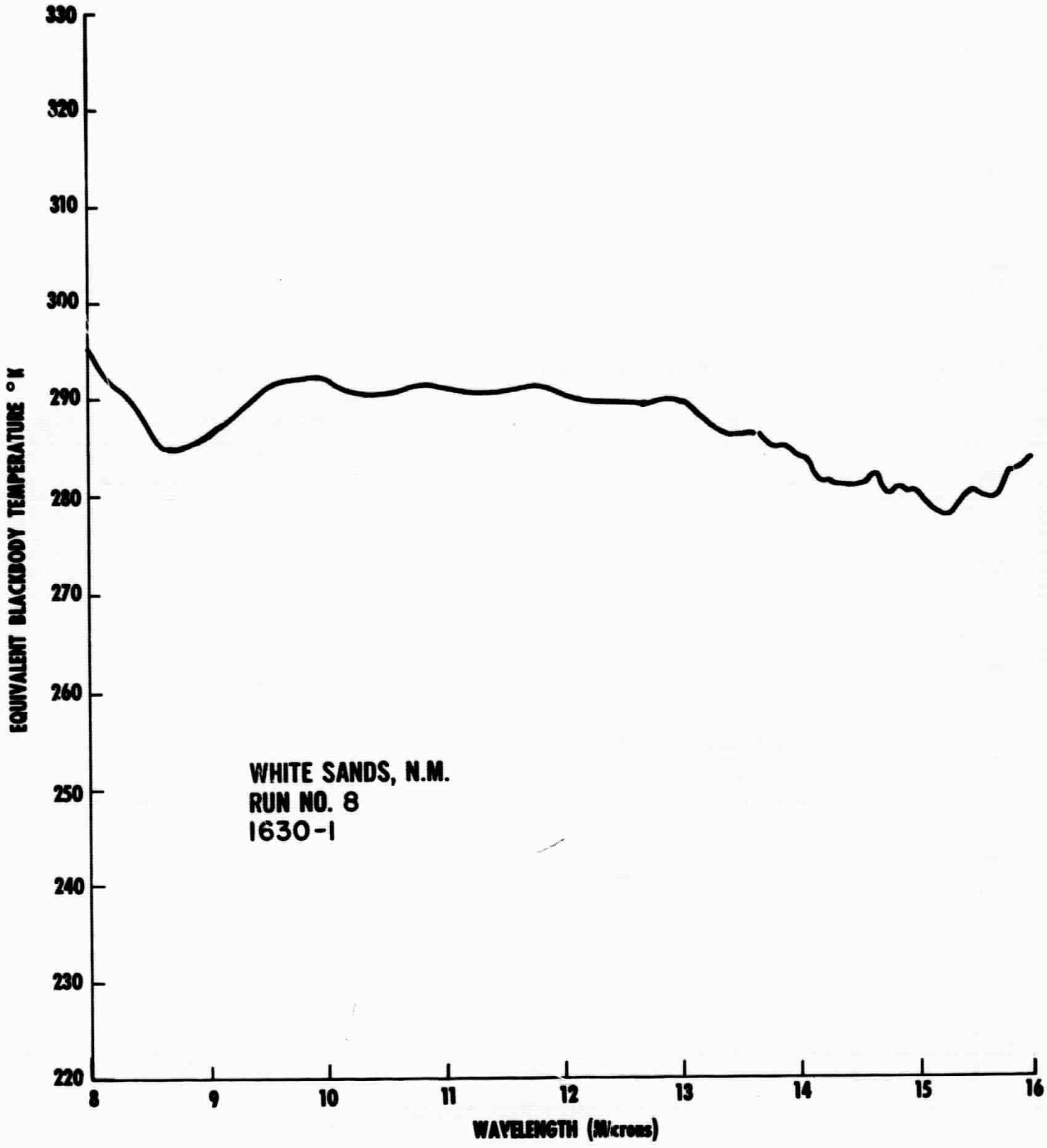
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 8
1629-2



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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 8
1630-1
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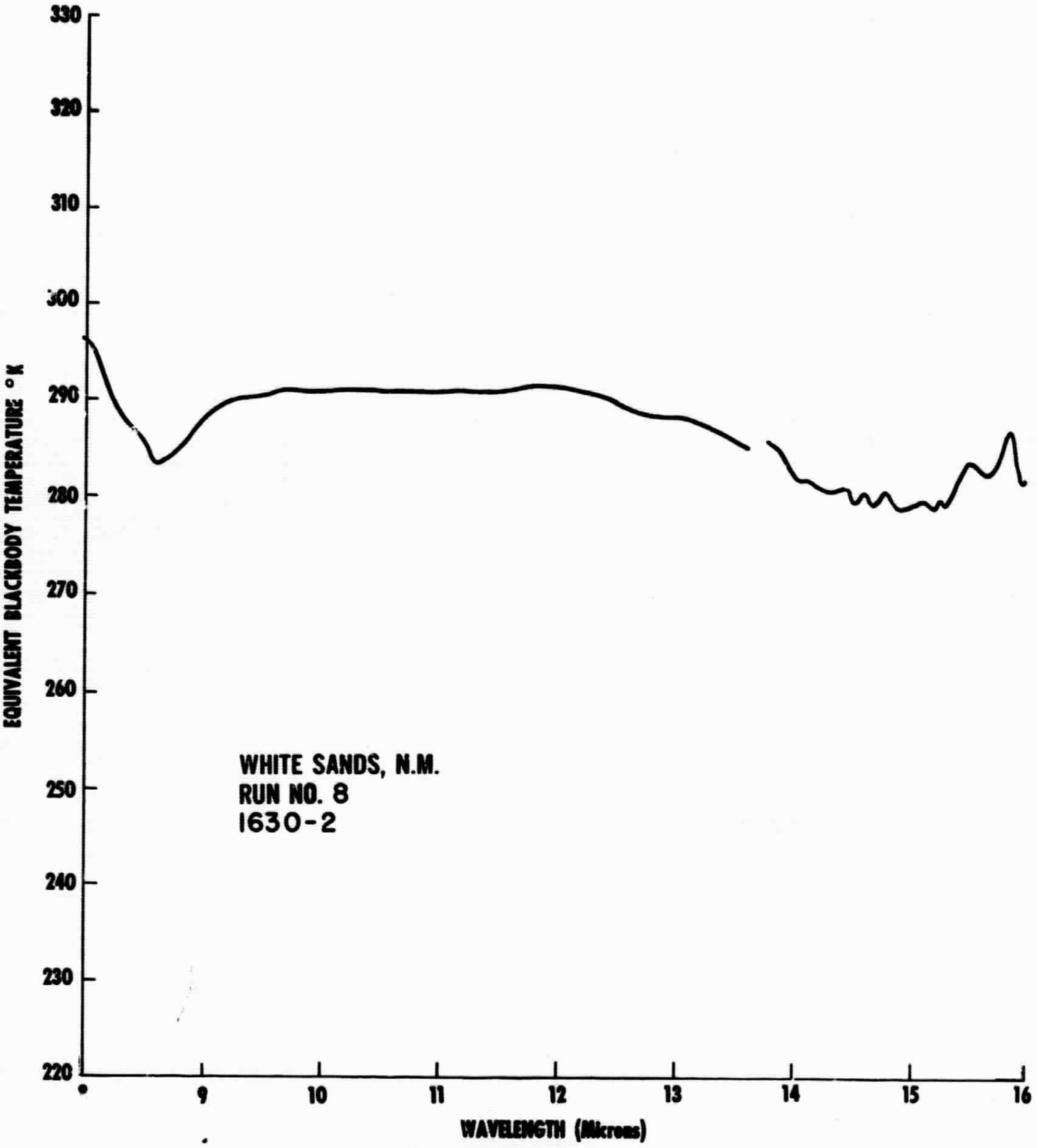
WAVELENGTH (Microns)



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EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 8
1630-2
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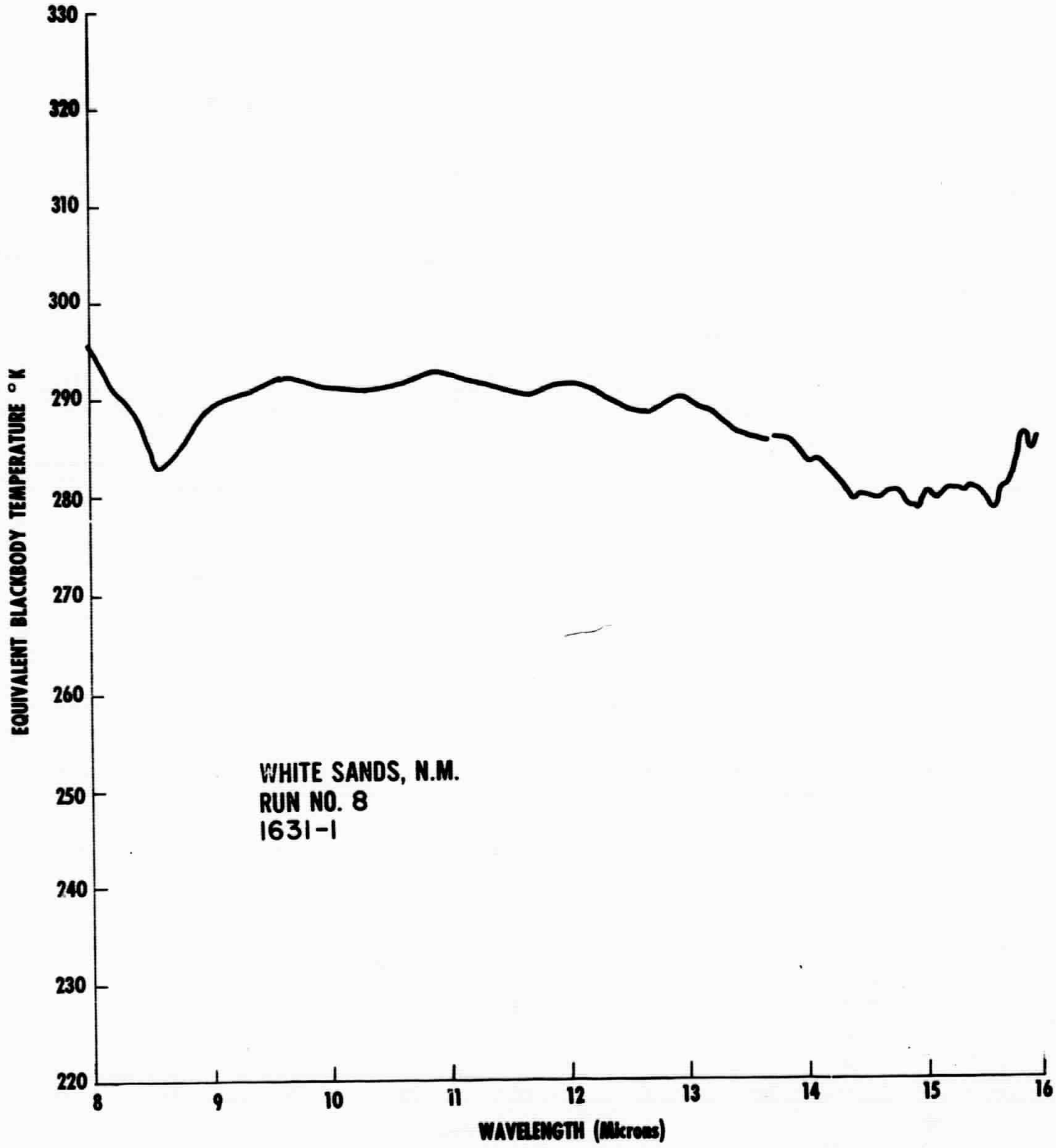
WAVELENGTH (Microns)



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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 8
1631-1
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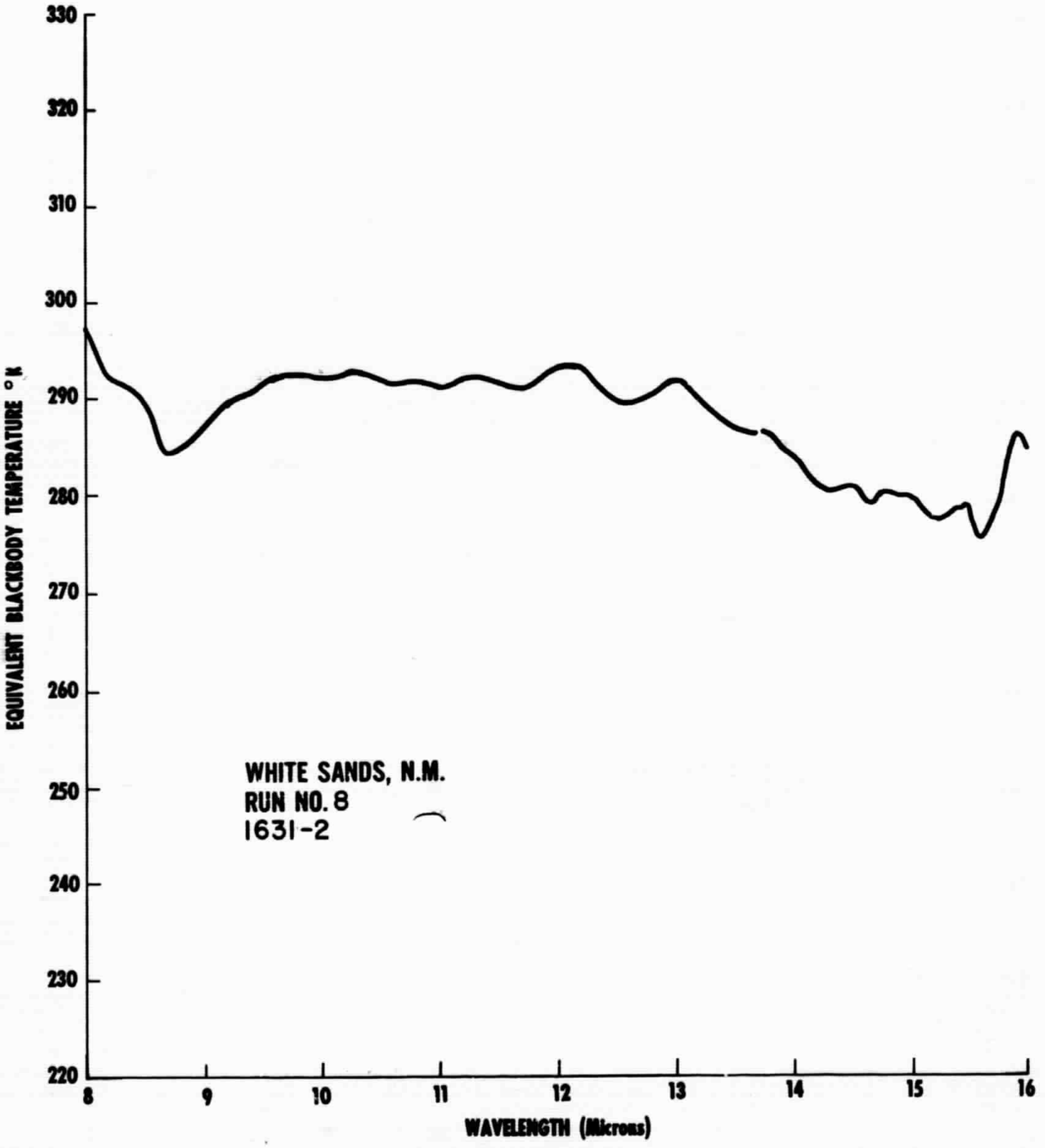
WAVELENGTH (Mikrons)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220
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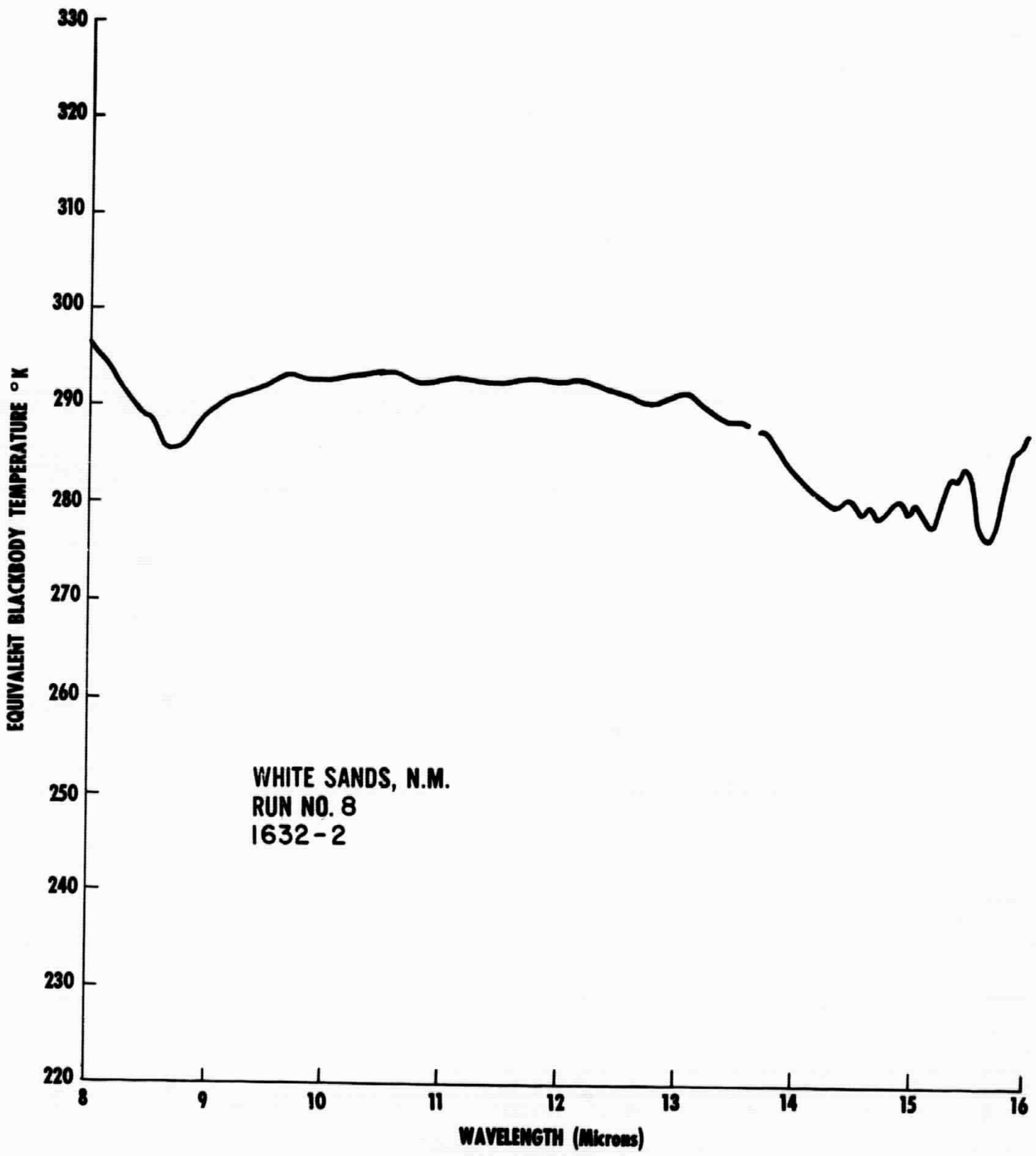
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 8
1631-2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EQUIVALENT BLACKBODY TEMPERATURE °K
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RUN NO. 8
1632-2
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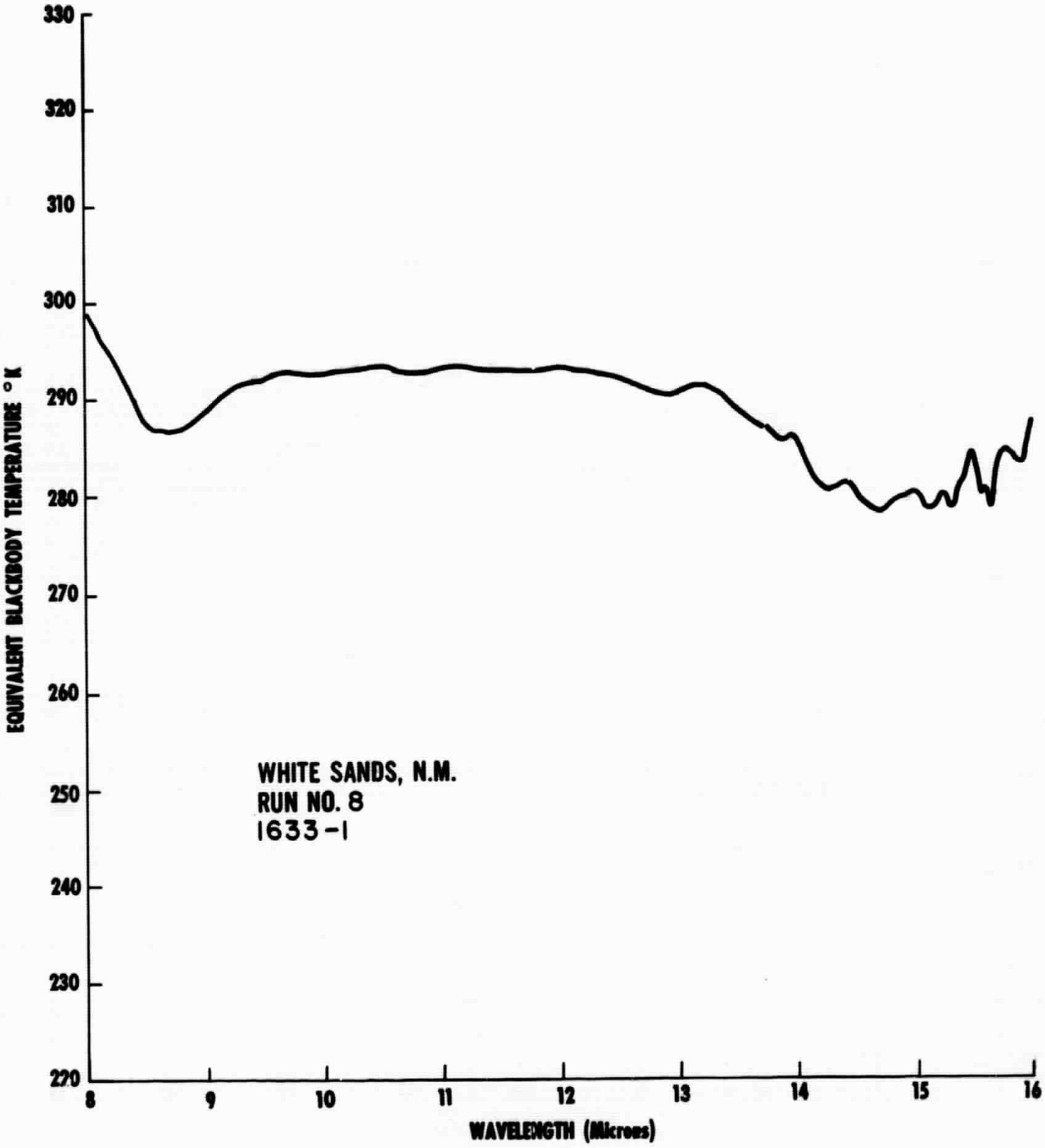
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE ° K
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RUN NO. 8
1633-1
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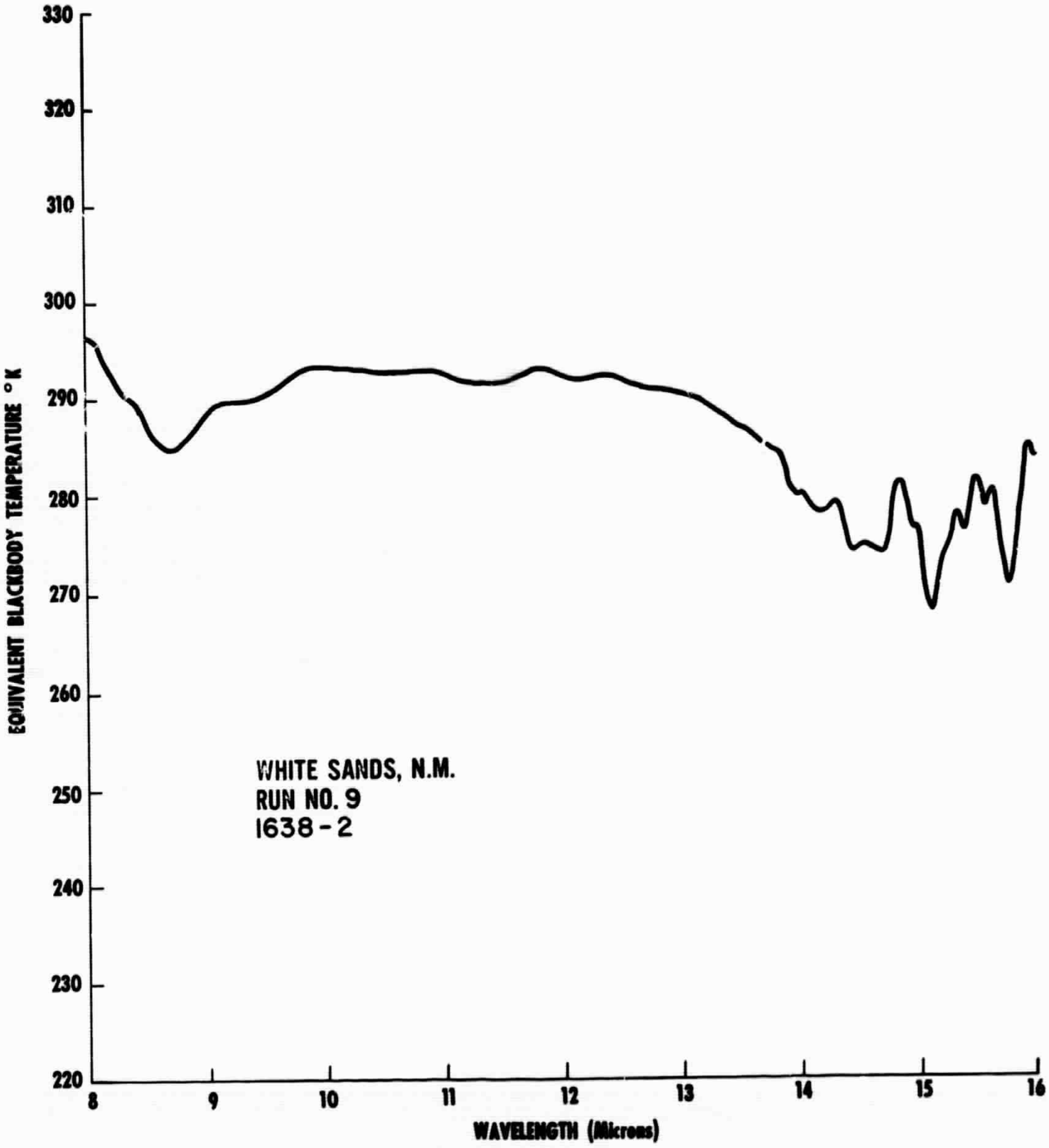
WAVELENGTH (Microns)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EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 9
1638-2
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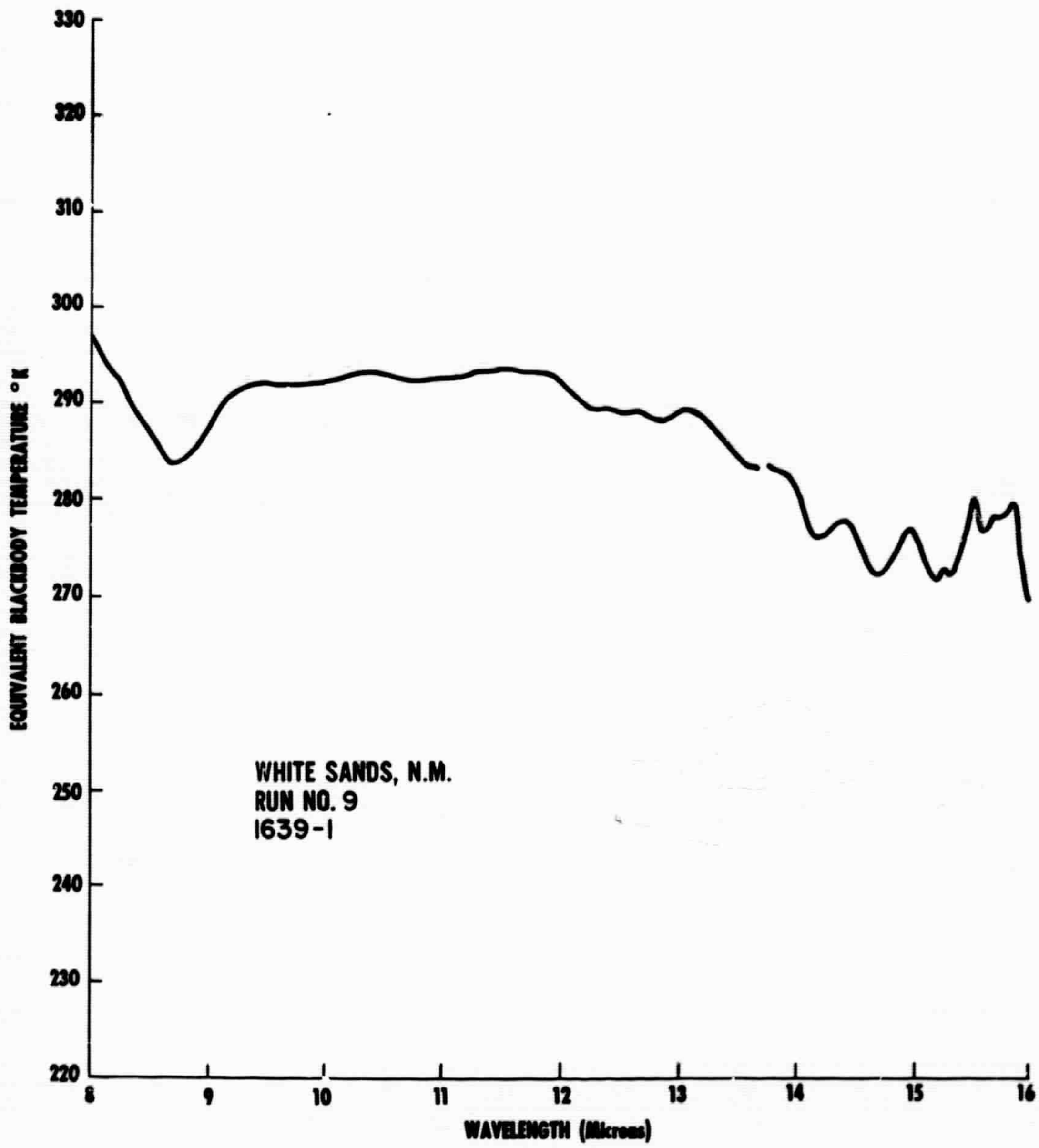
16
WAVELENGTH (Microns)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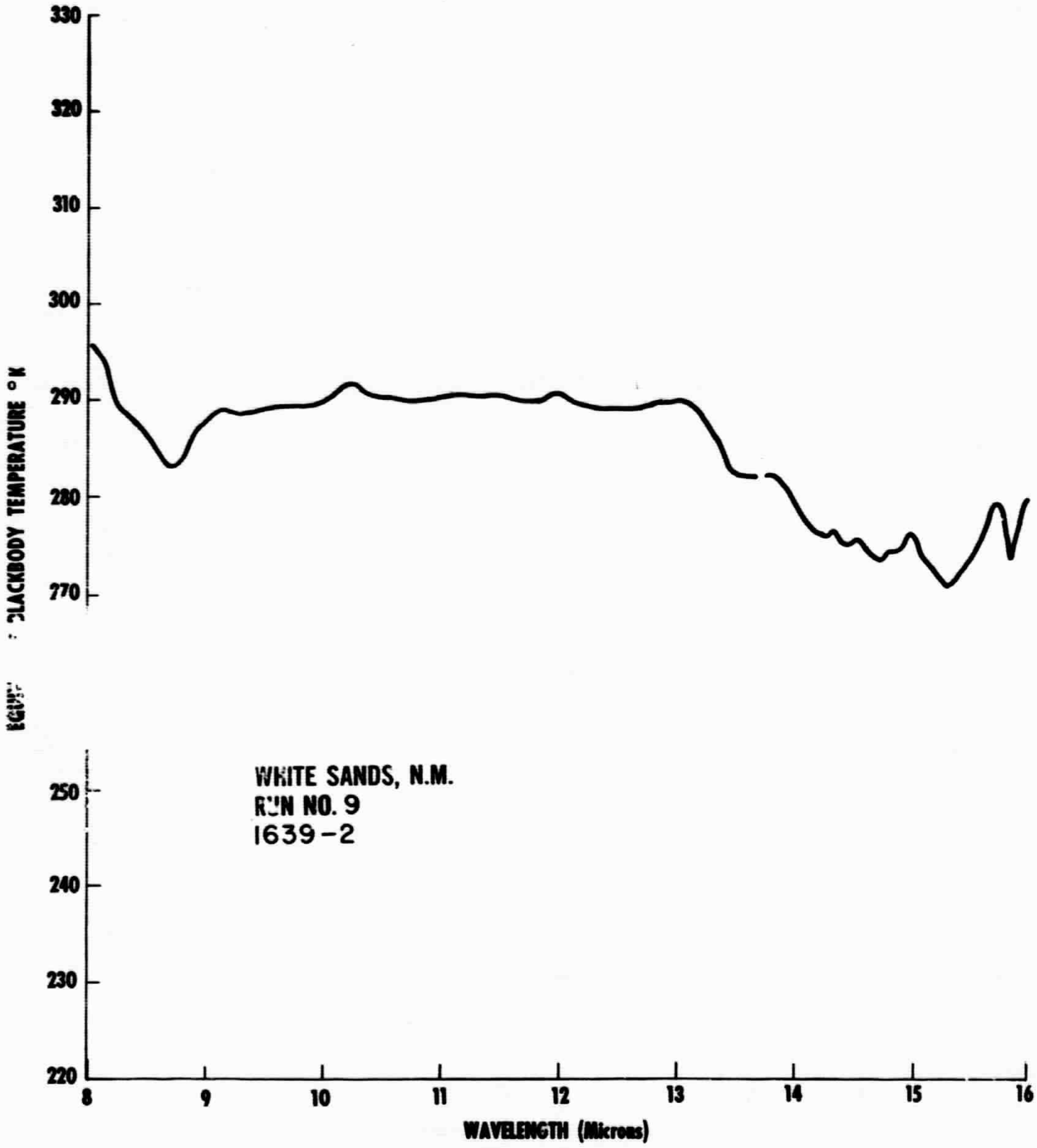
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 9
1639-1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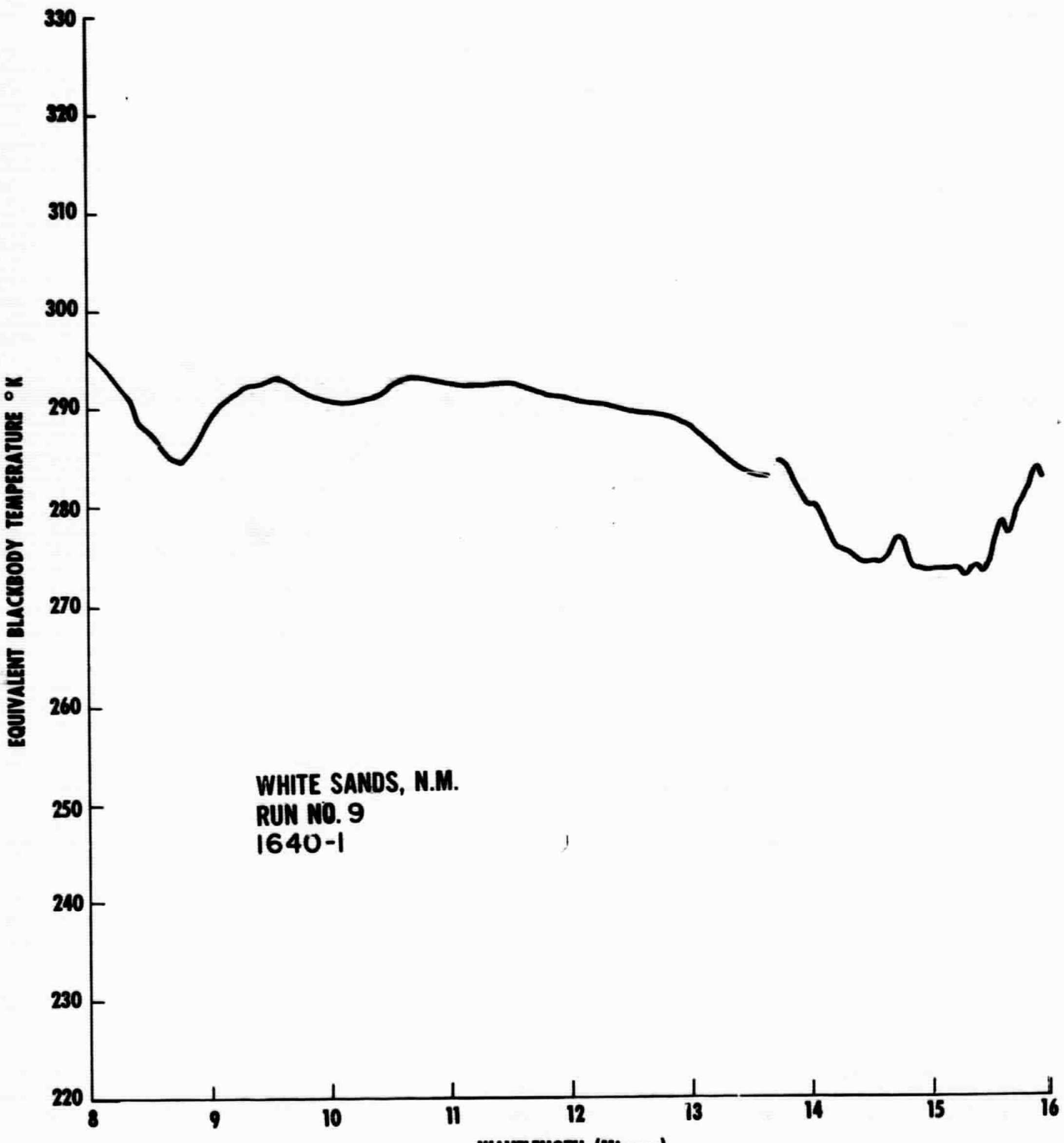
WAVELENGTH (Microns)
BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 9
1639-2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220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 9
1640-1
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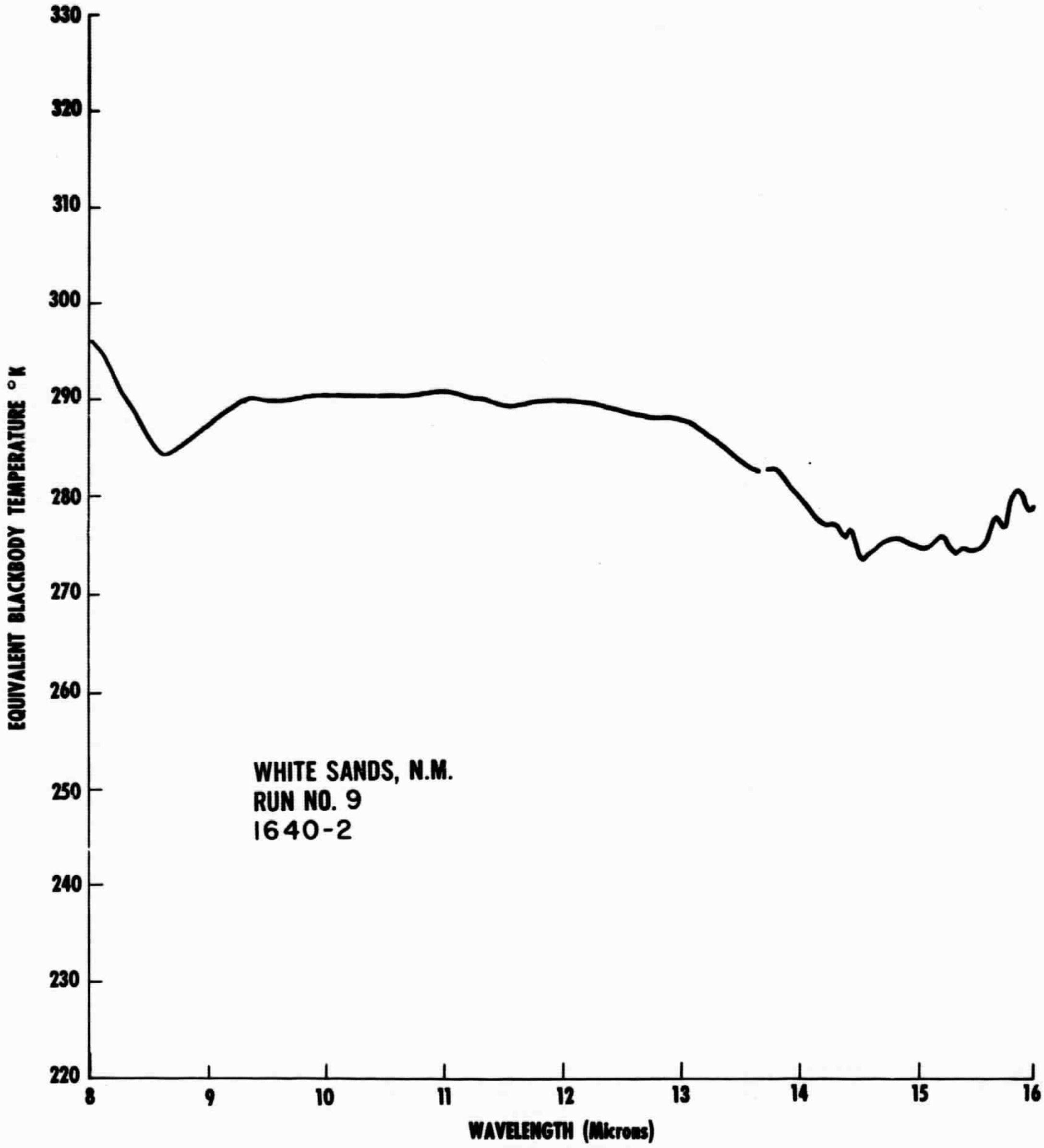
16
WAVELENGTH (Microns)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220
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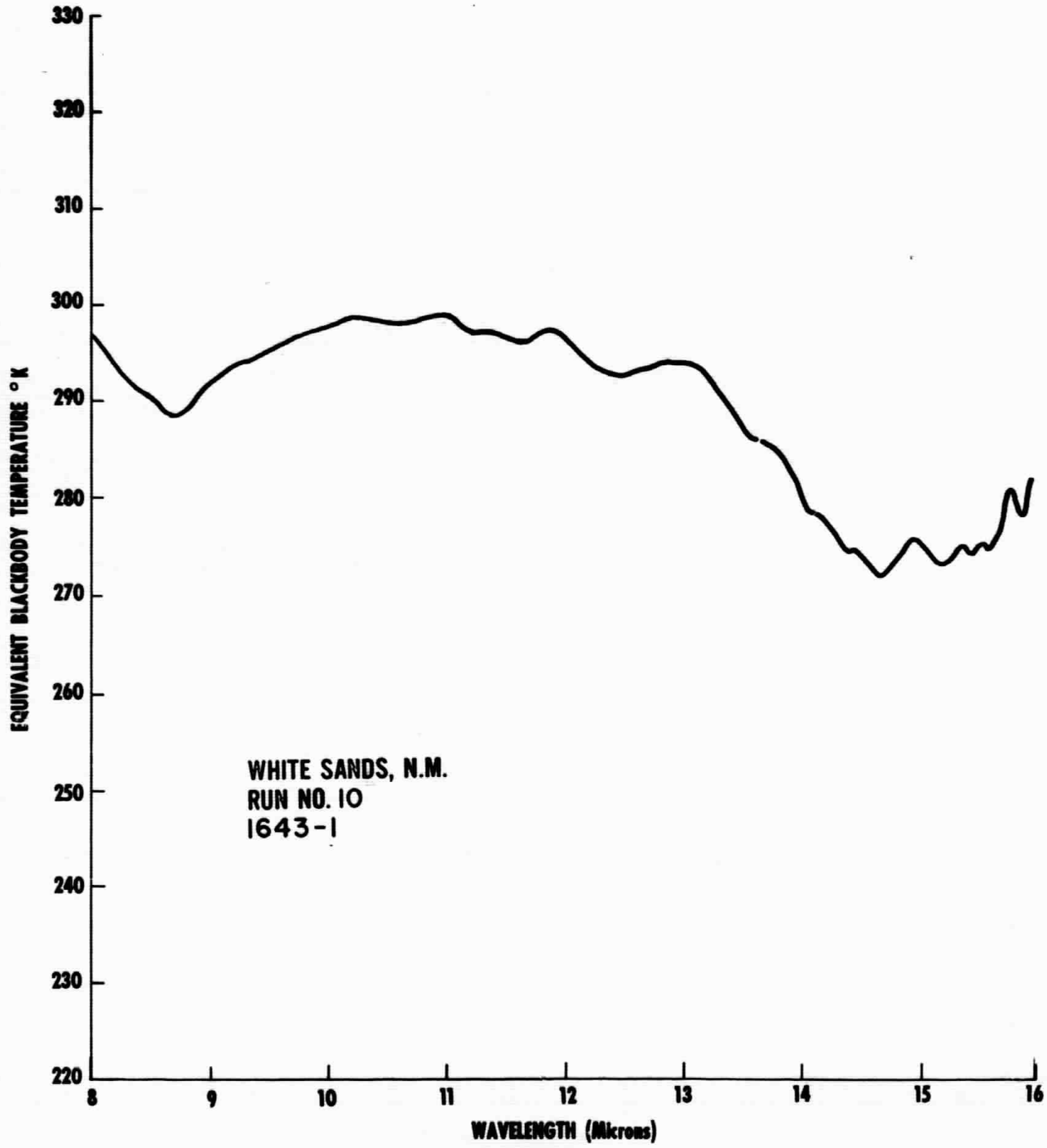
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 9
1640-2



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220
EQUIVALENT BLACKBODY TEMPERATURE °K
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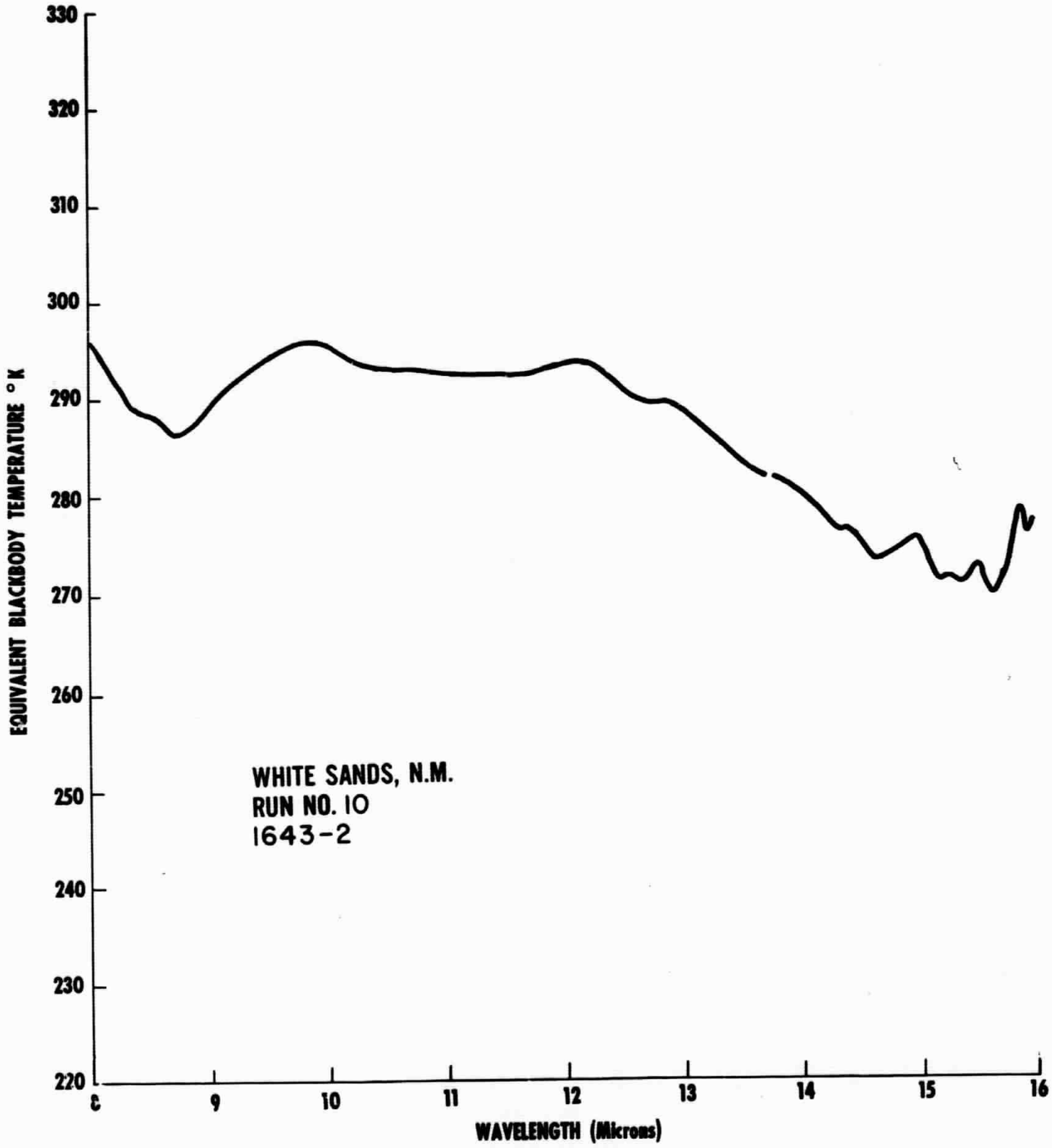
16
WAVELENGTH (Microns)
WHITE SANDS, N.M.
RUN NO. 10
1643-1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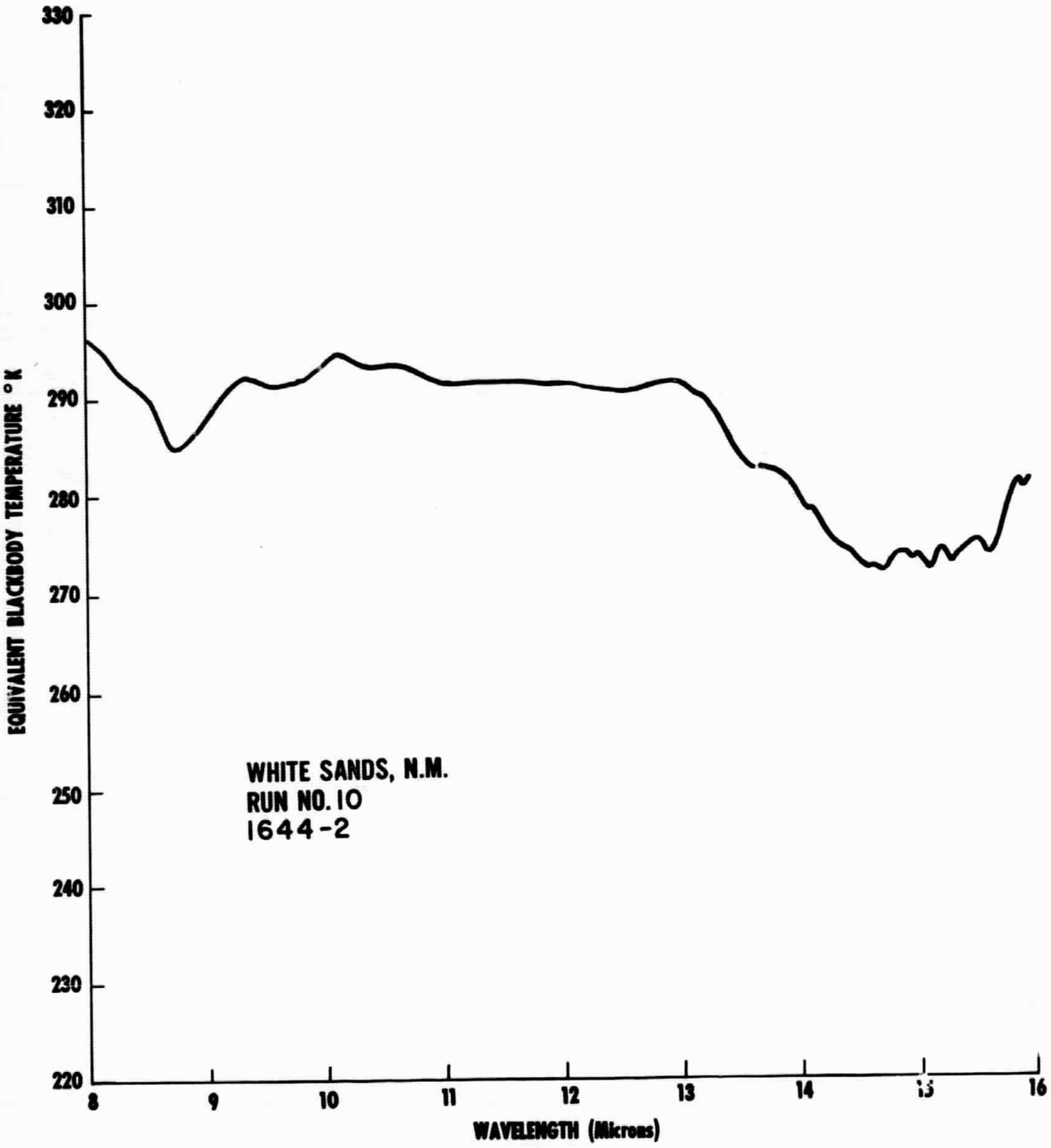
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 10
1643-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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290
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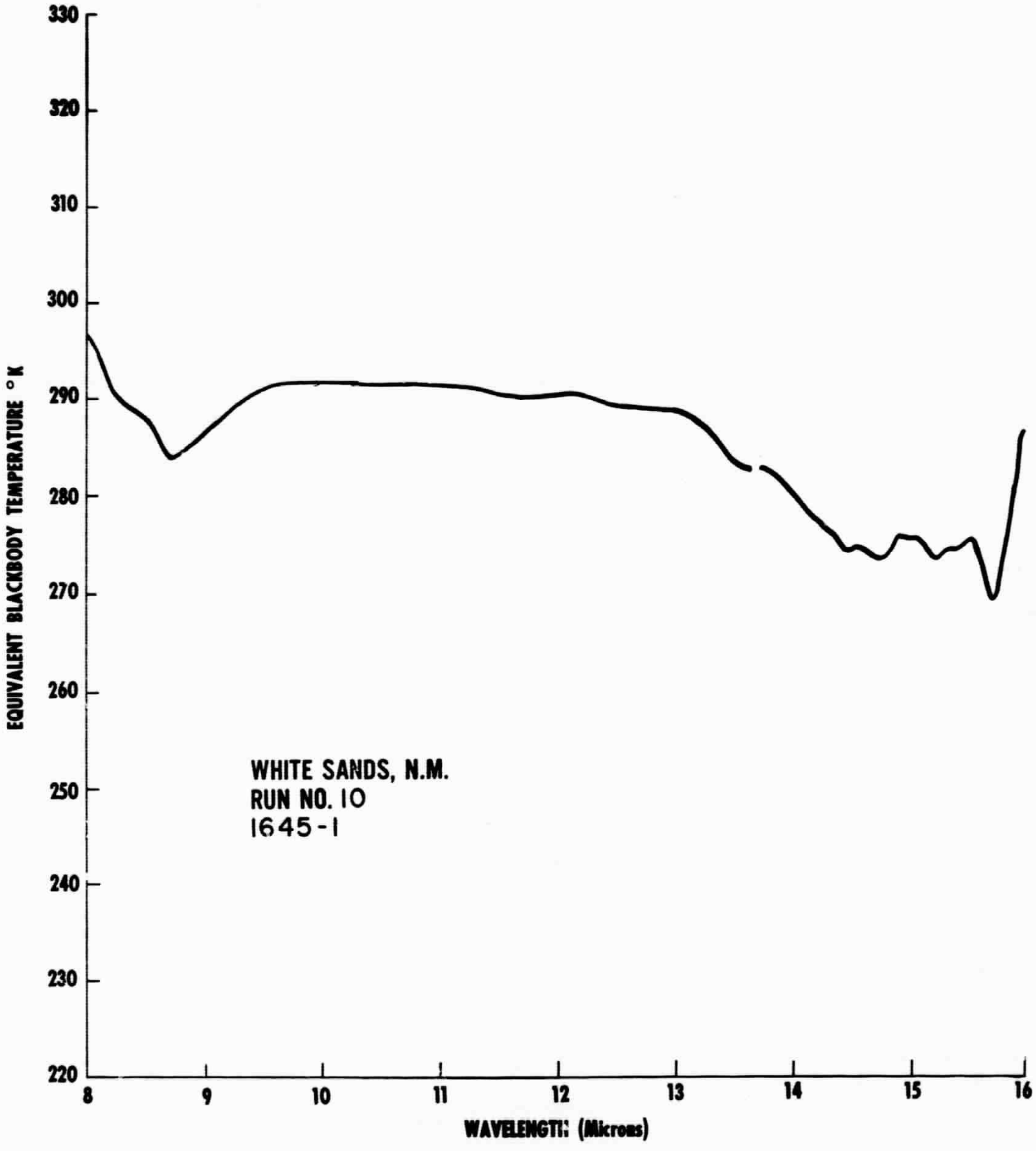
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 10
1644-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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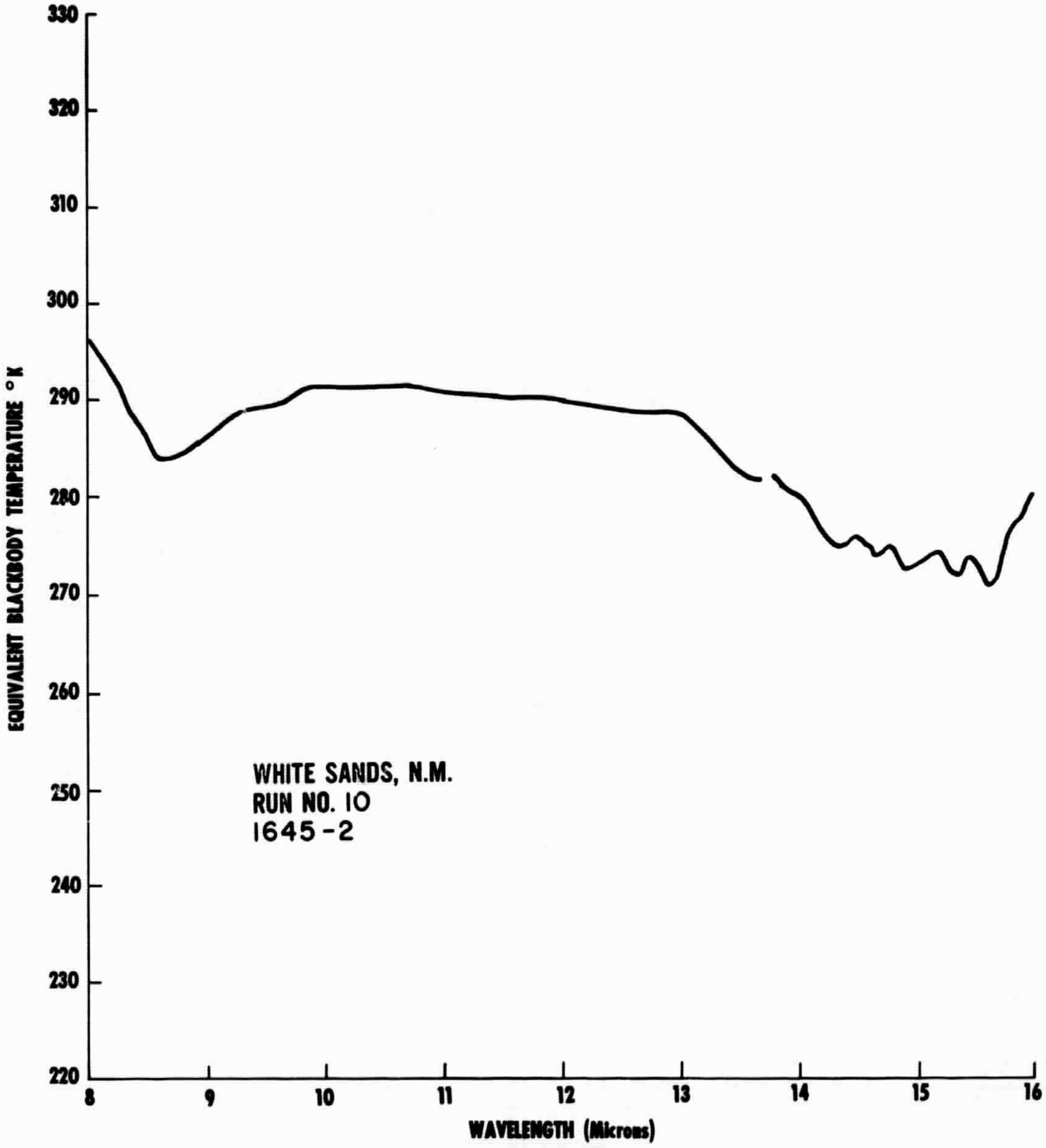
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 10
1645-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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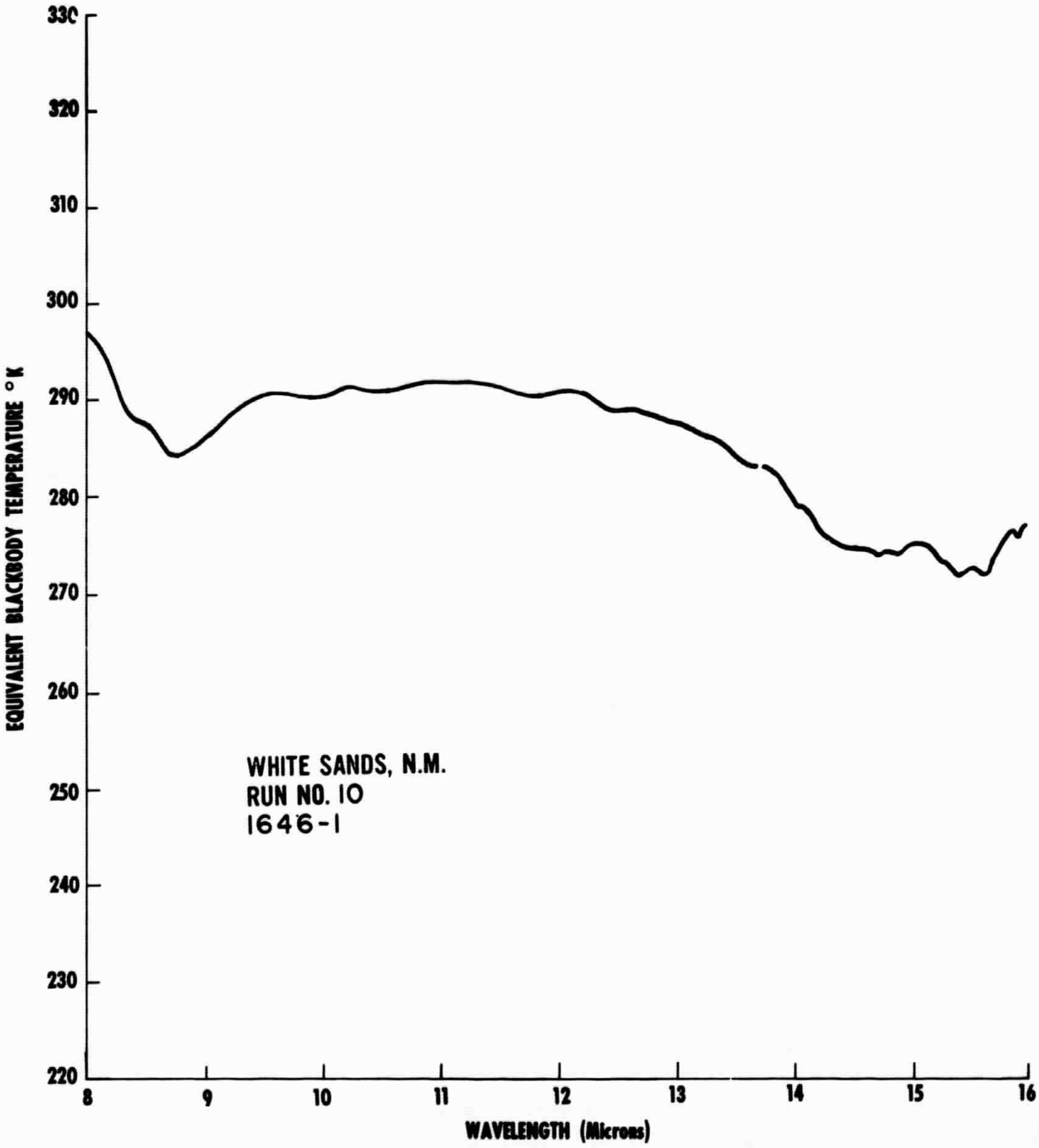
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 10
1645-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
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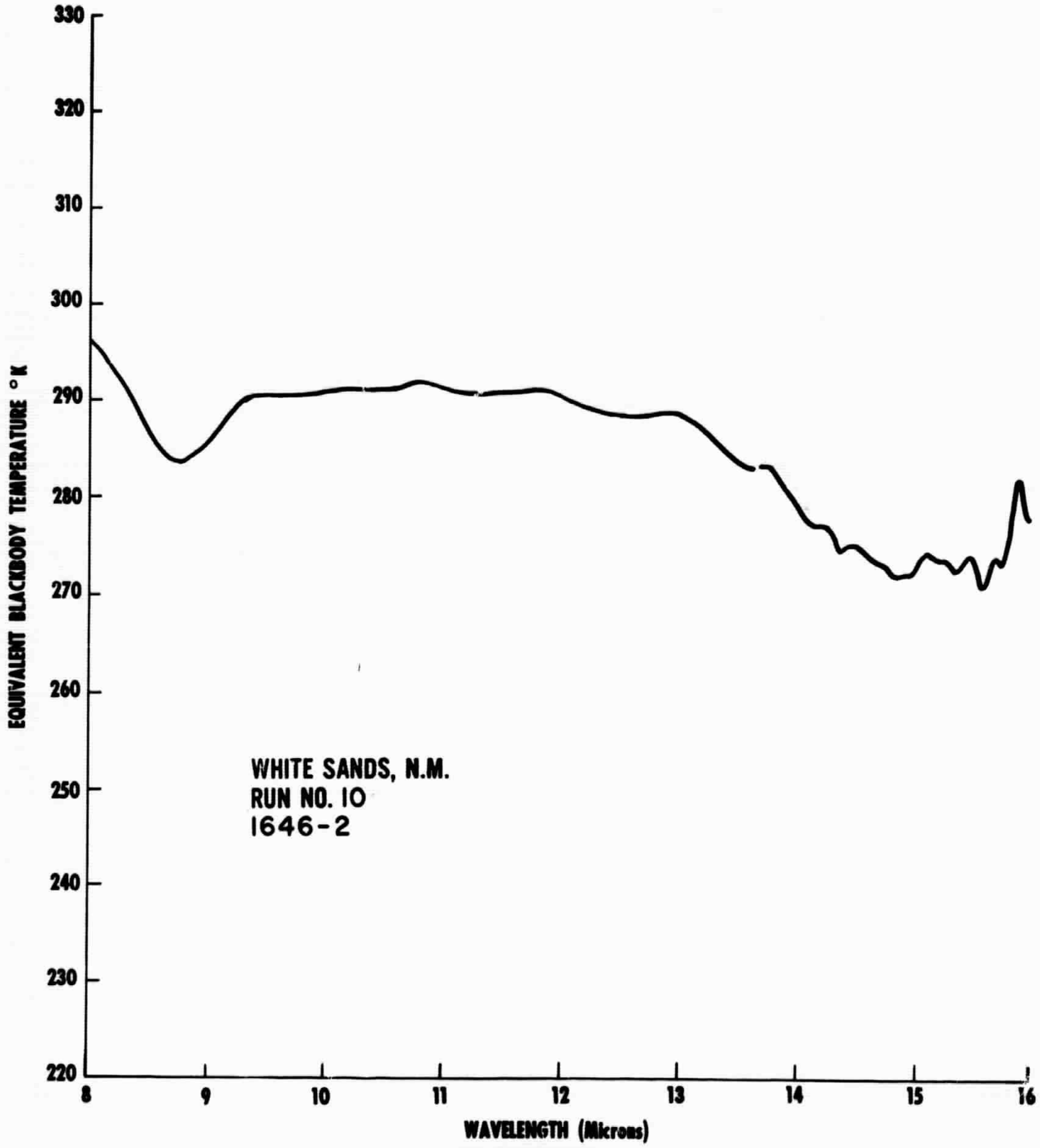
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 10
1646-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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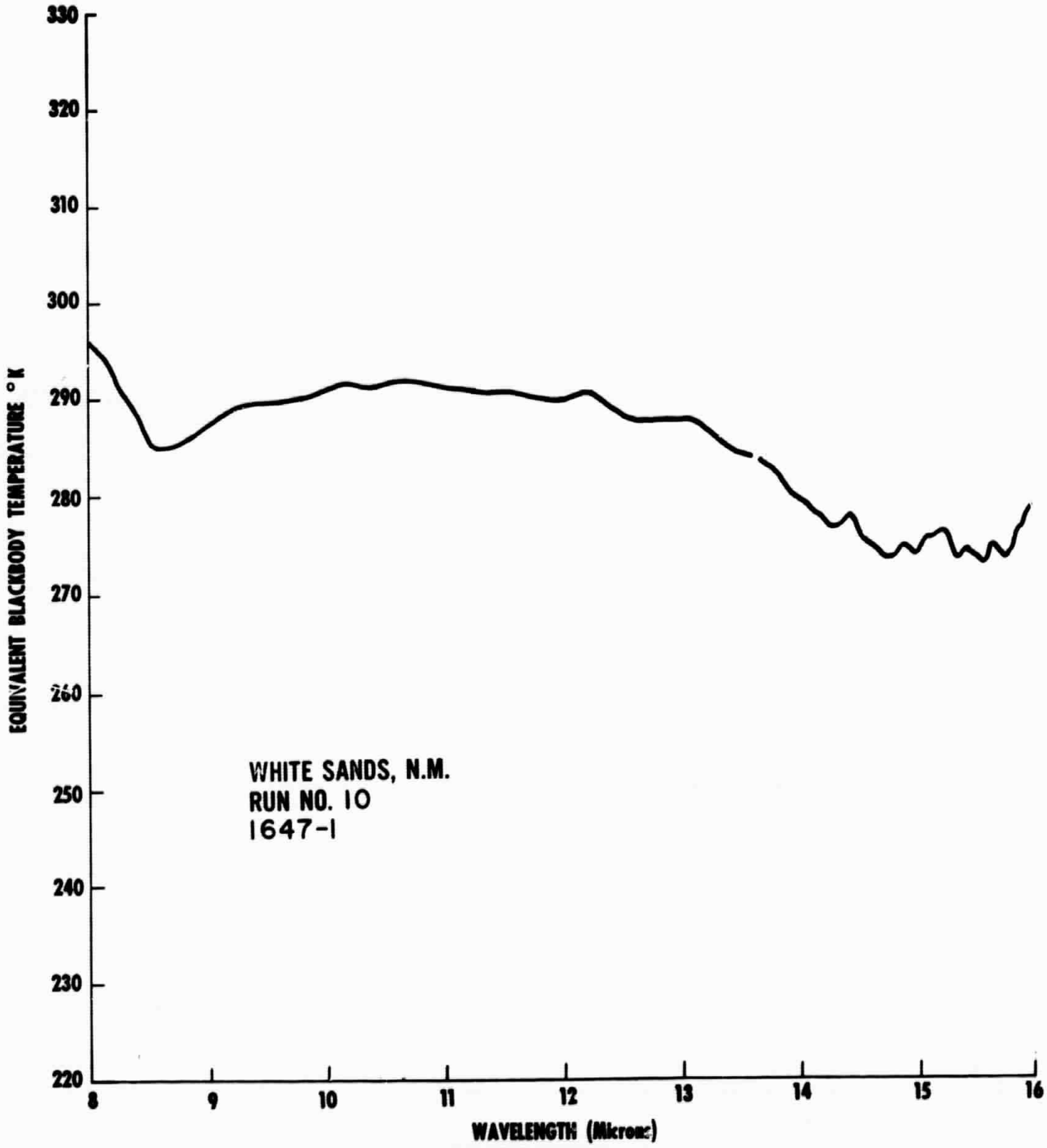
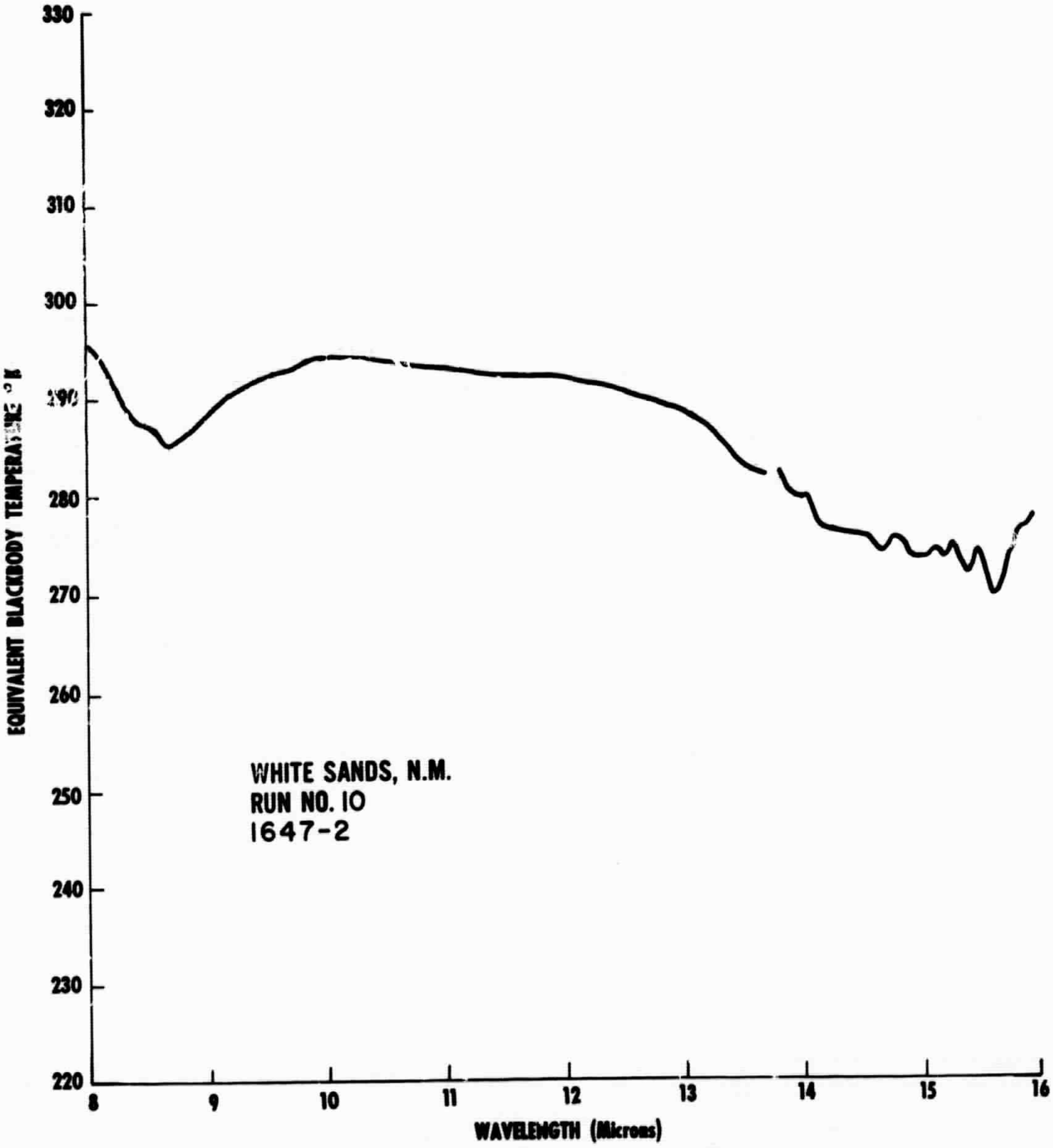
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
WHITE SANDS, N.M.
RUN NO. 10
1646-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
WHITE SANDS, N.M.
RUN NO. 10
1647-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
300
290
280
270
260
250
240
230
220
WHITE SANDS, N.M.
RUN NO. 10
1647-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

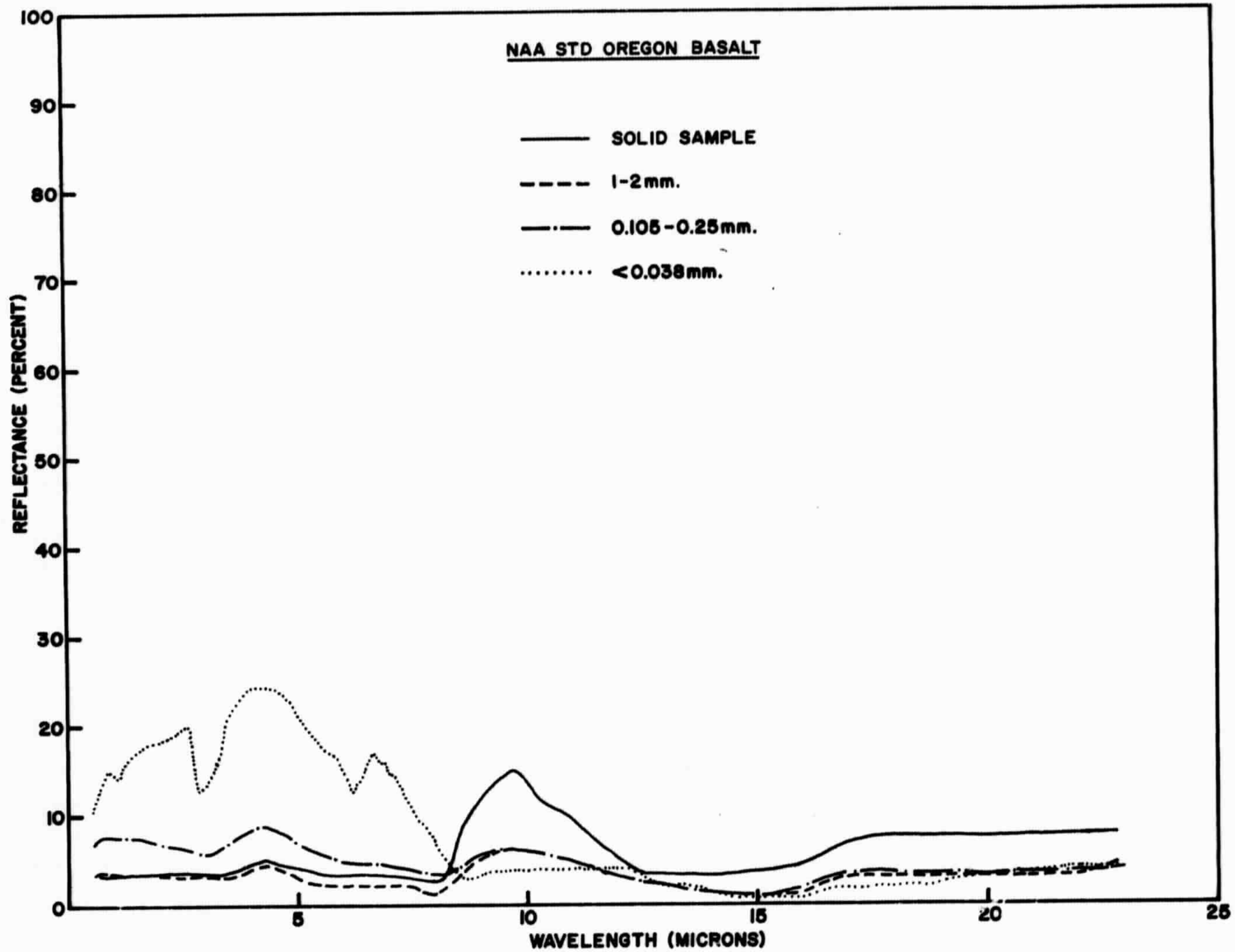

NAA STD OREGON BASALT
SOLID SAMPLE
1-2mm.
0.105-0.25mm.
<0.038mm.
REFLECTANCE (PERCENT)
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
WAVELENGTH (MICRONS)

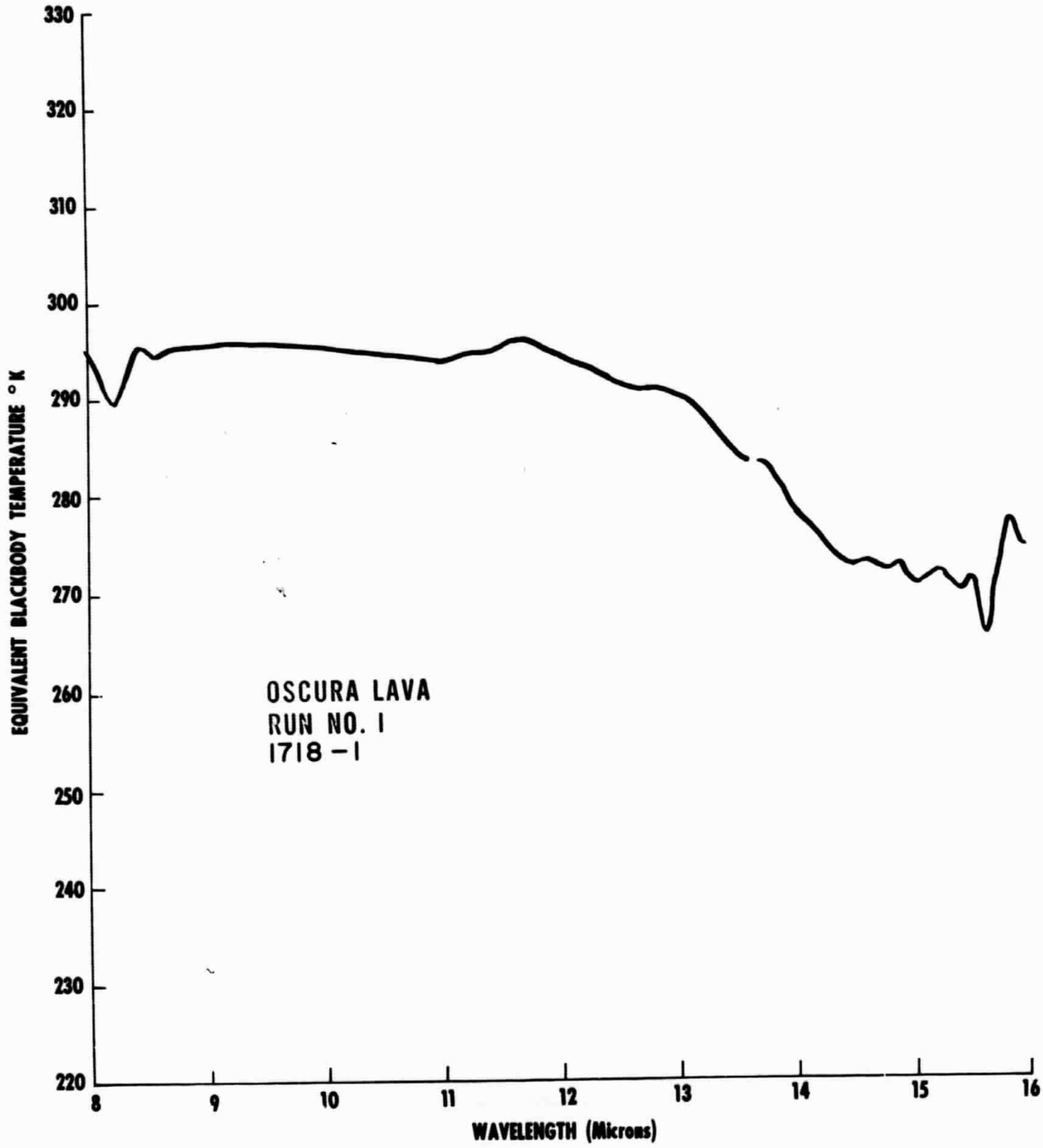
Figure 5

Table 2

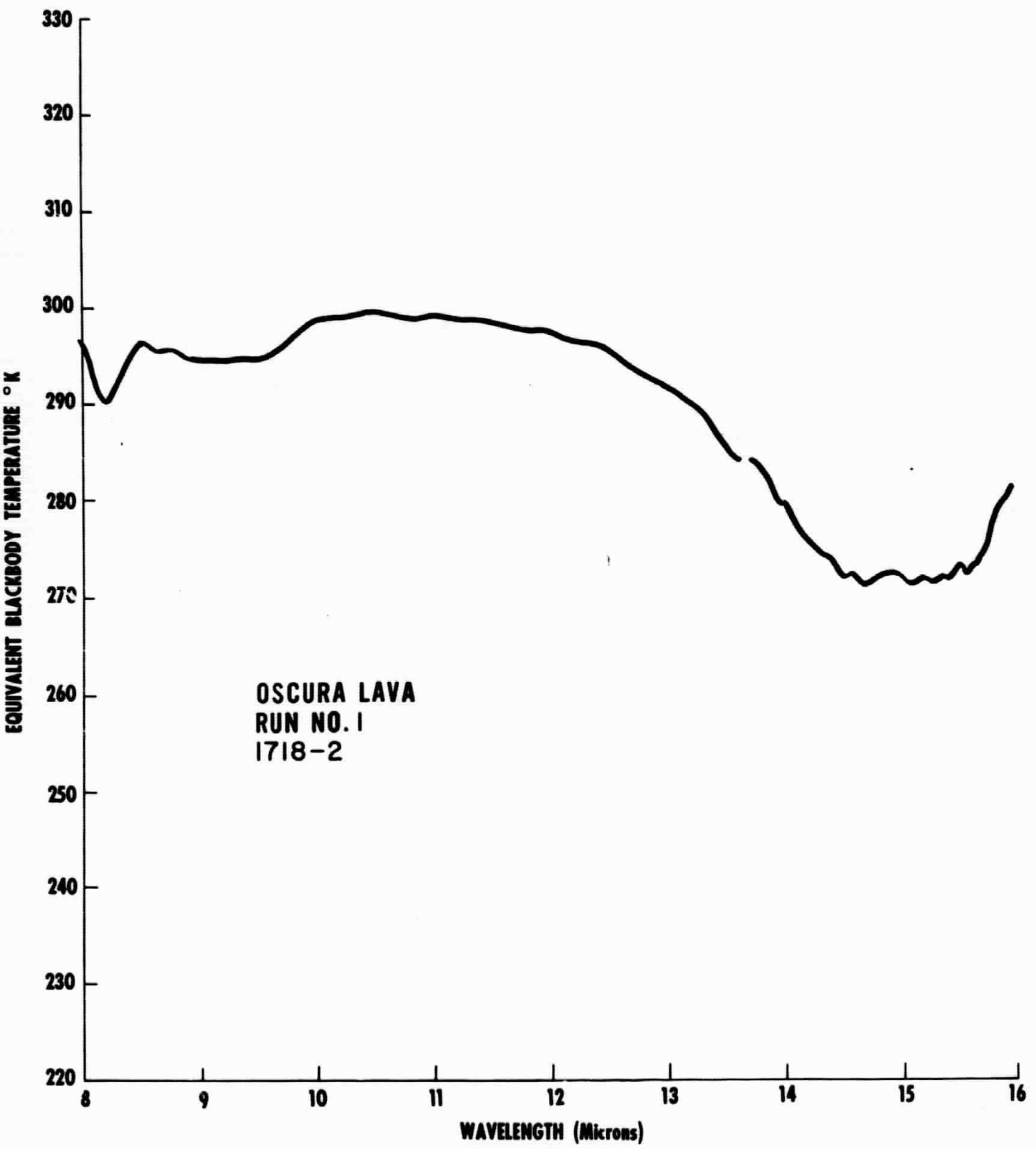
Aircraft: C47 NASA 636
Target: The Malpais Lava Flow

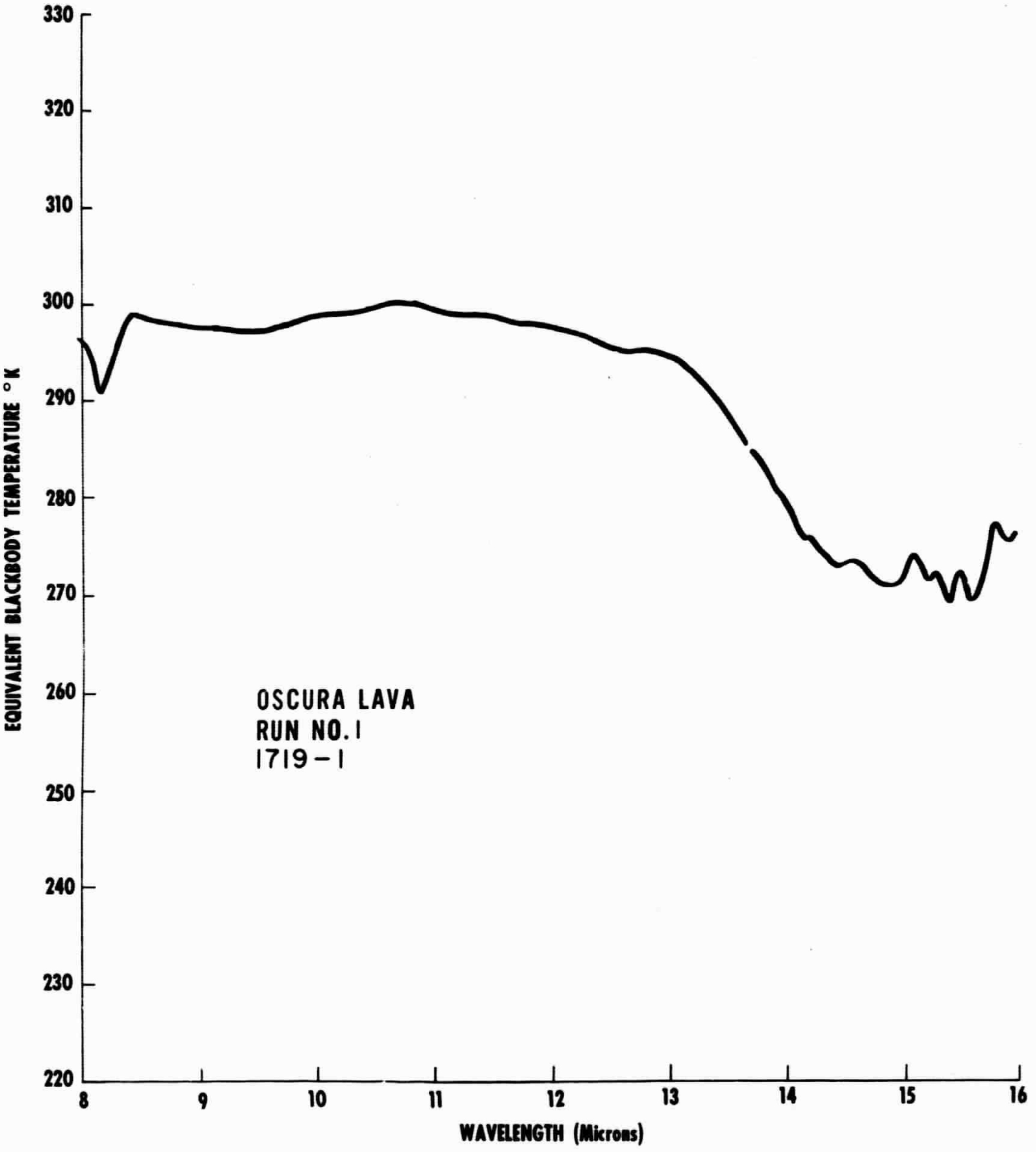
Date: Oct 15, 1967
Instrument: F.W.S. 8 to 16 Microus

Run Number	Time (U.T.)	Altitude (kft)	Outside Temp. °C	Remarks
1	1718 1722	13	-2	North to South
2	1730 1735	11	1	South to North
3	1742 1746	9	1	North to South
4	1752 1800	7	1	South to North

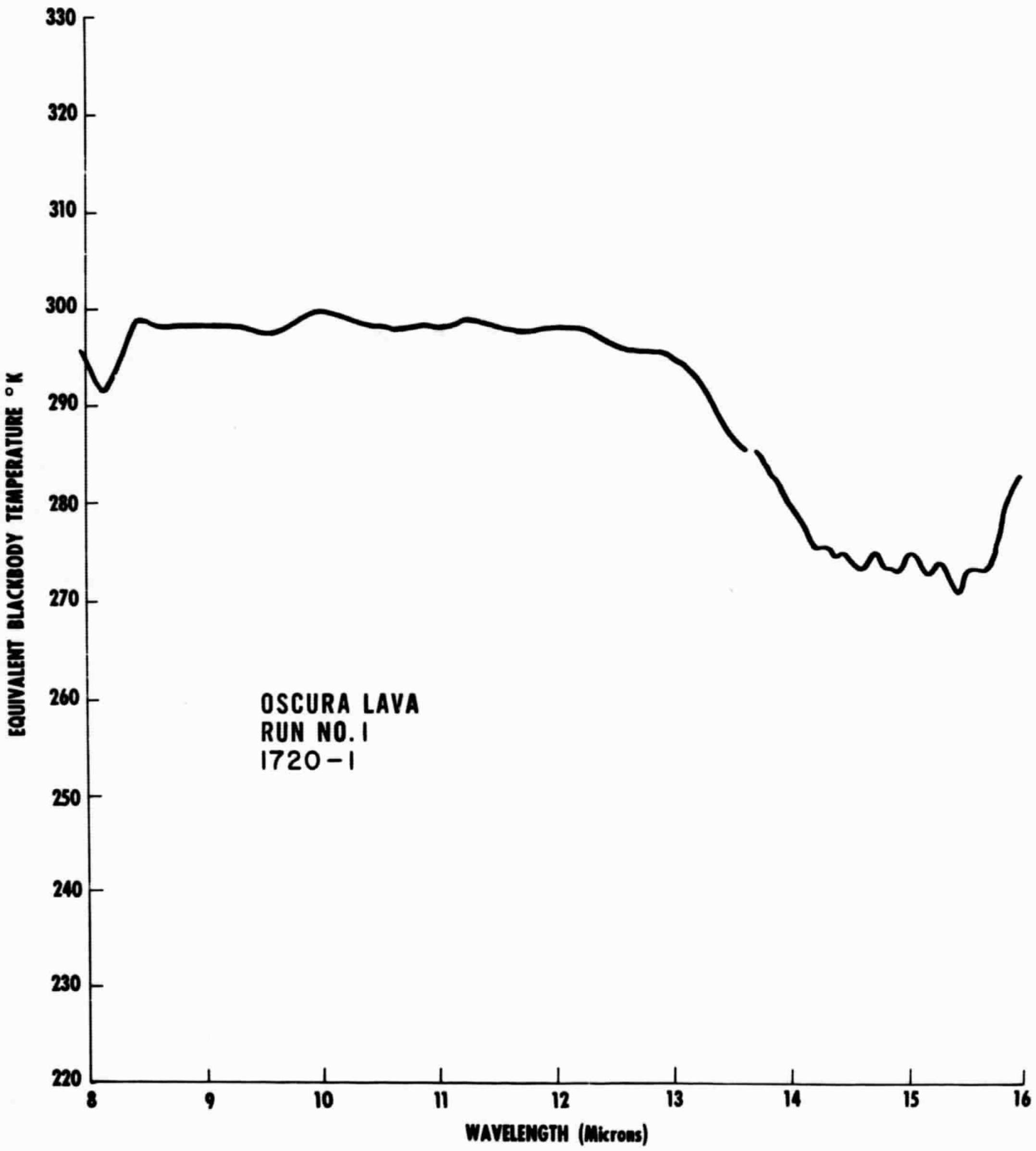


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 1
1718 -1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

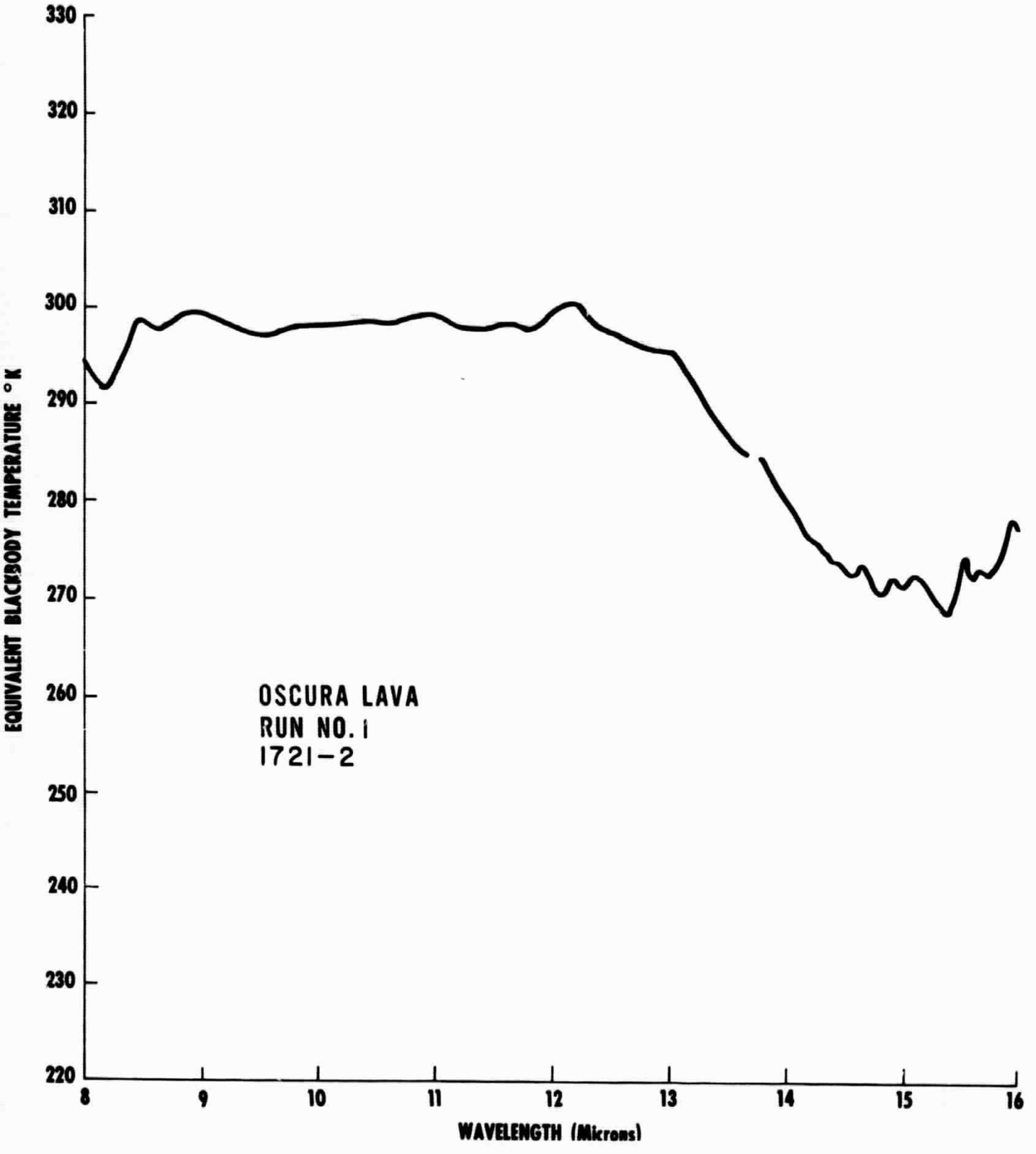

EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
300
290
280
270
260
250
240
230
220
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 1
1718-2

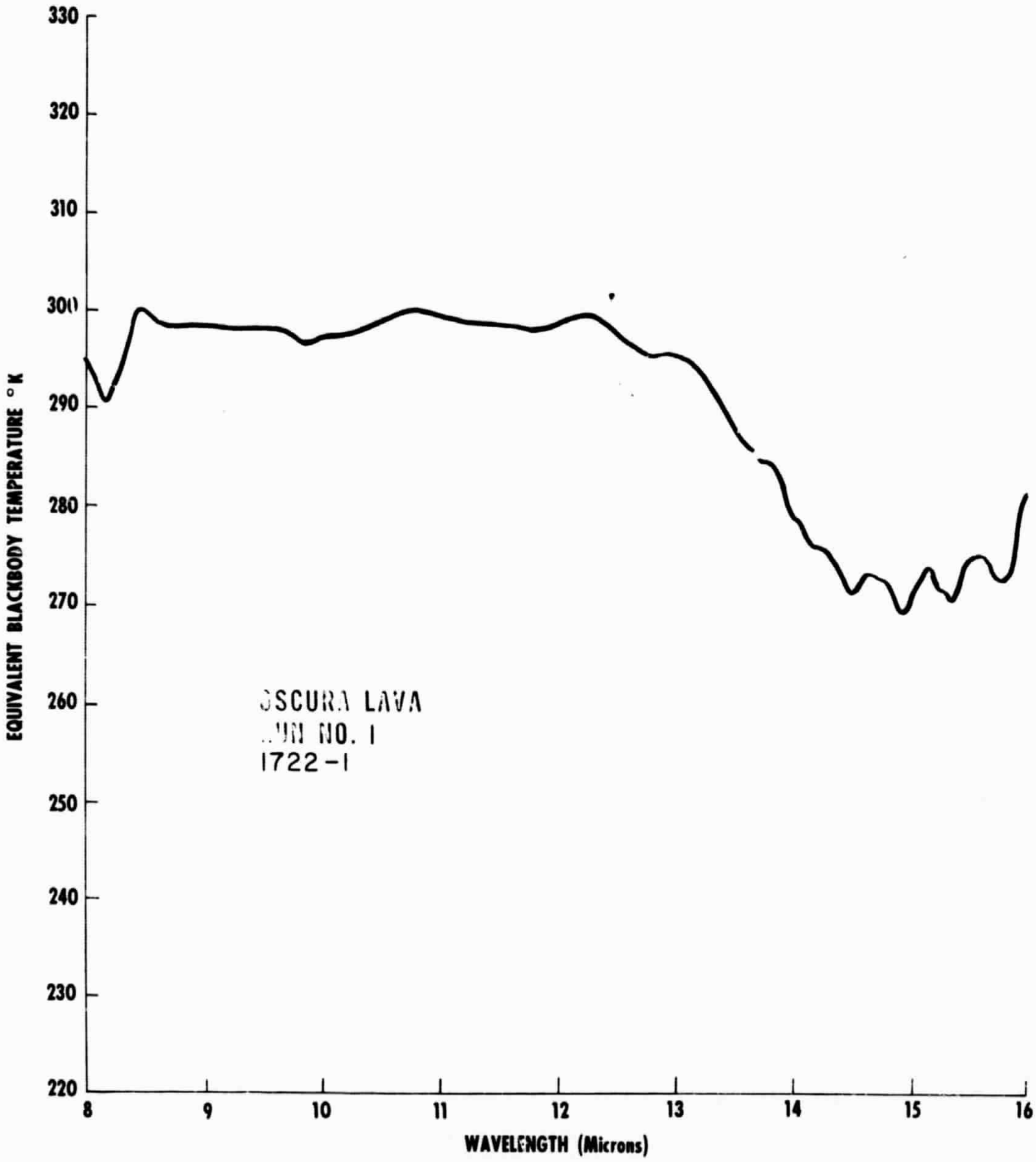


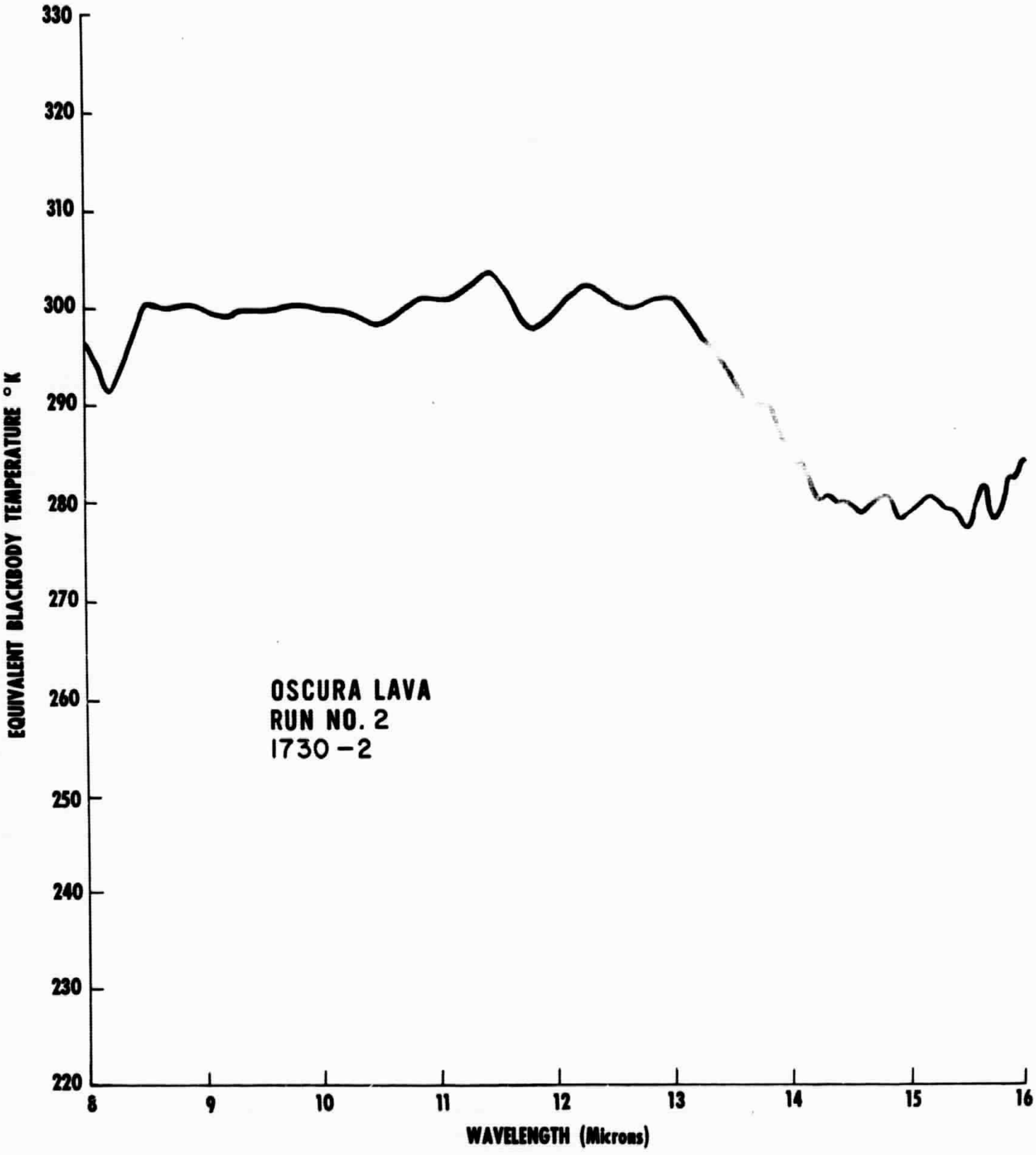
330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. I
1719 – I
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

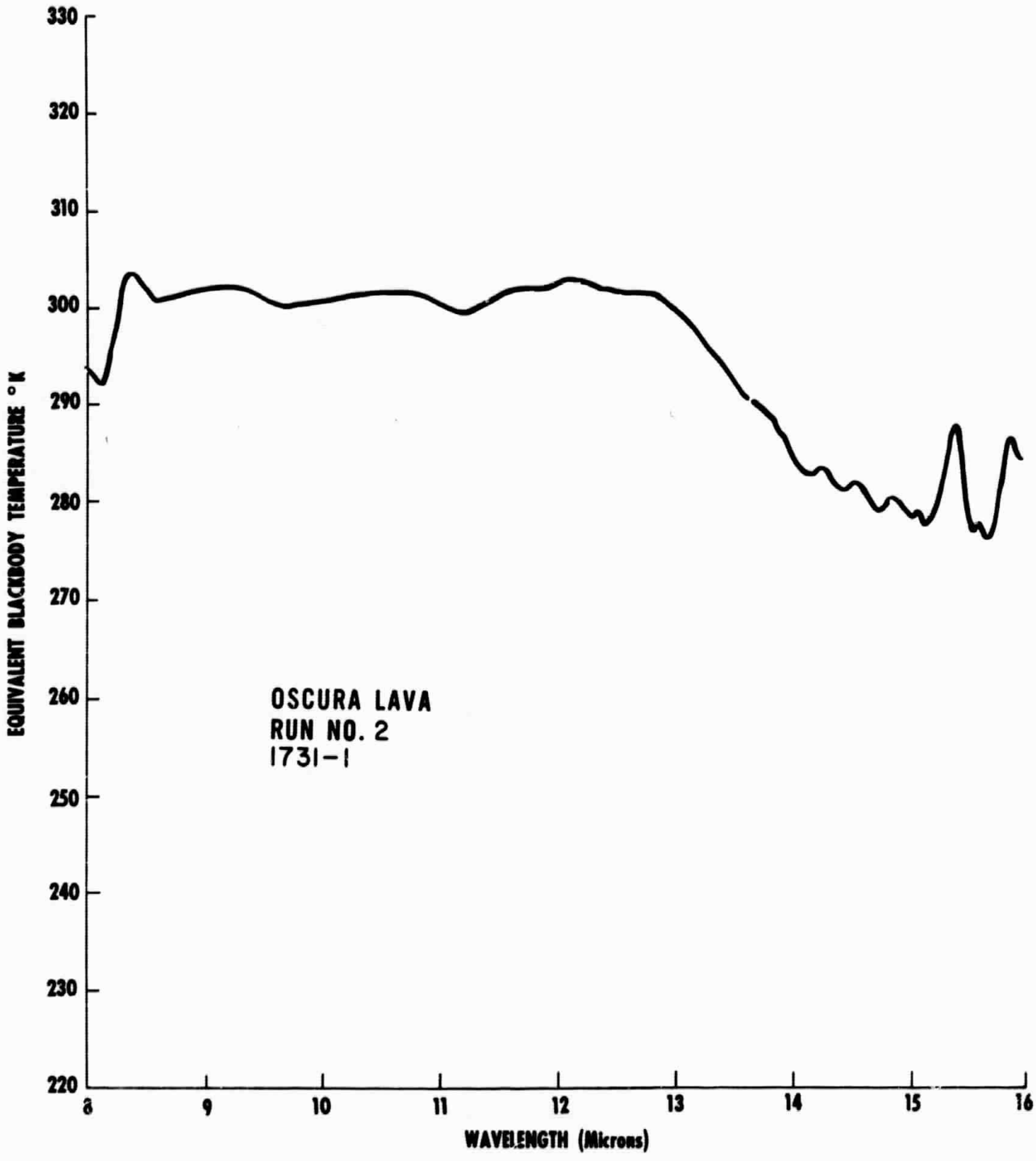

330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 1
1720-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. I
1720-2

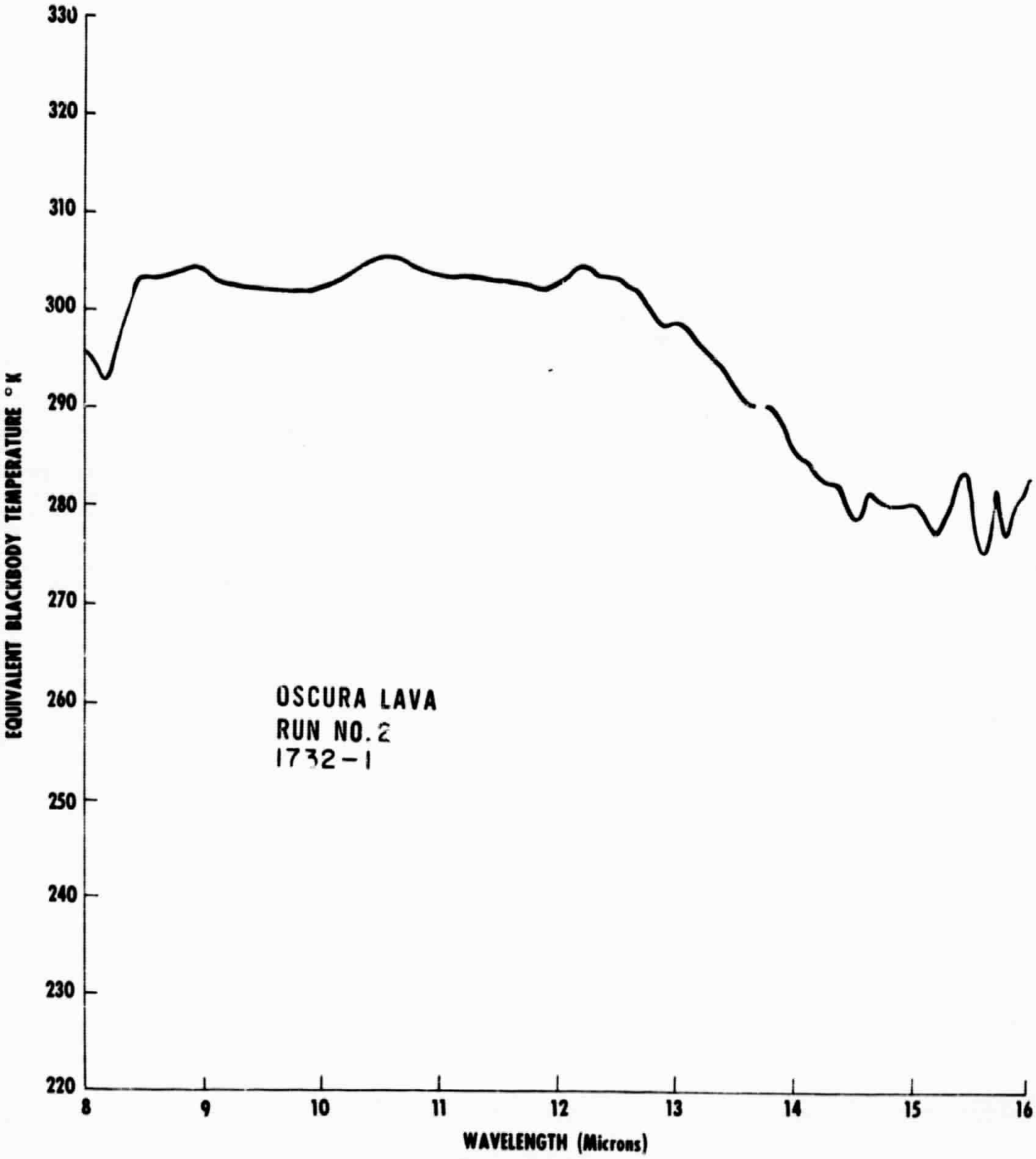

330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 1
1721-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 1
1722-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

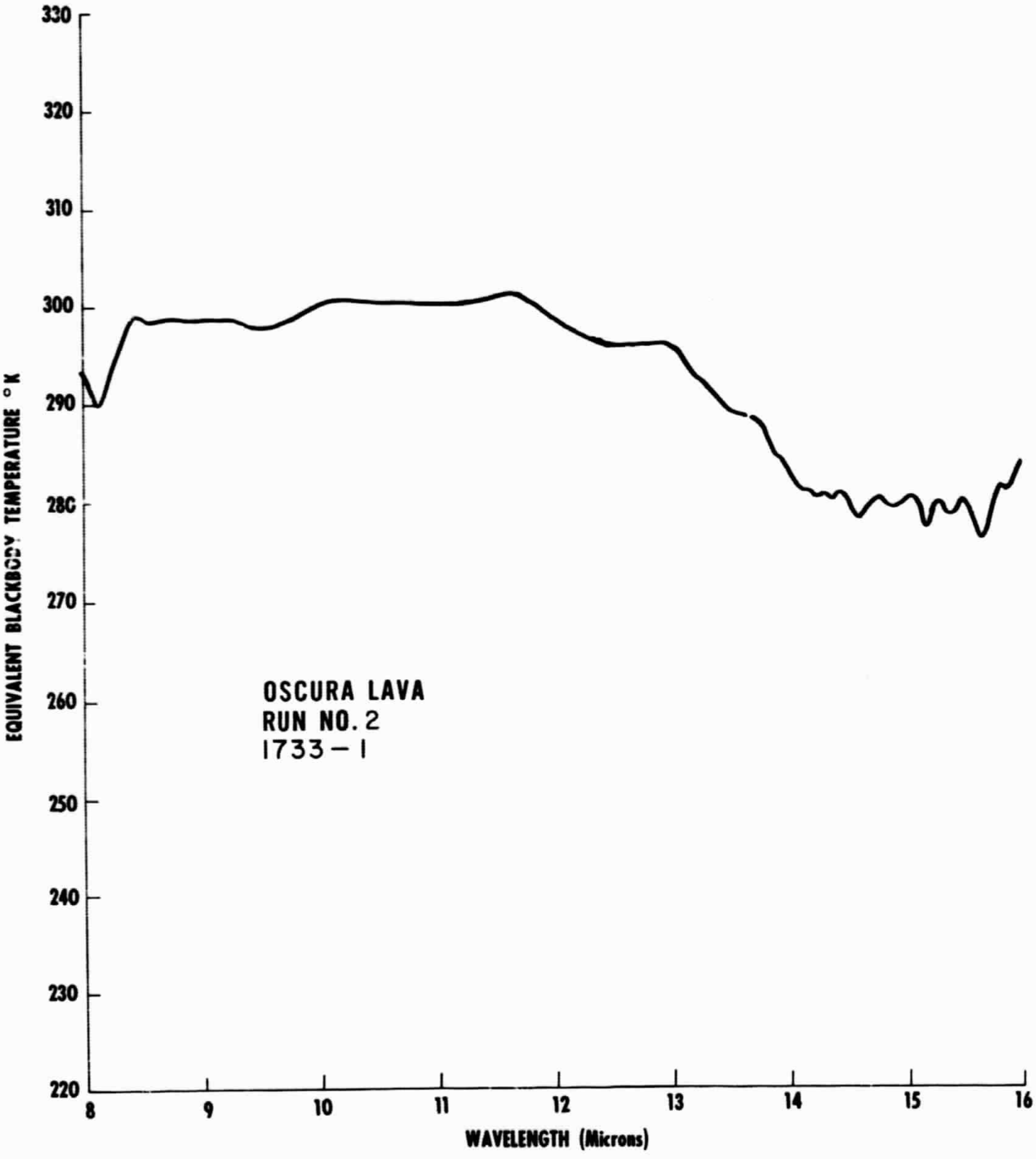

330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 2
1730 -2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

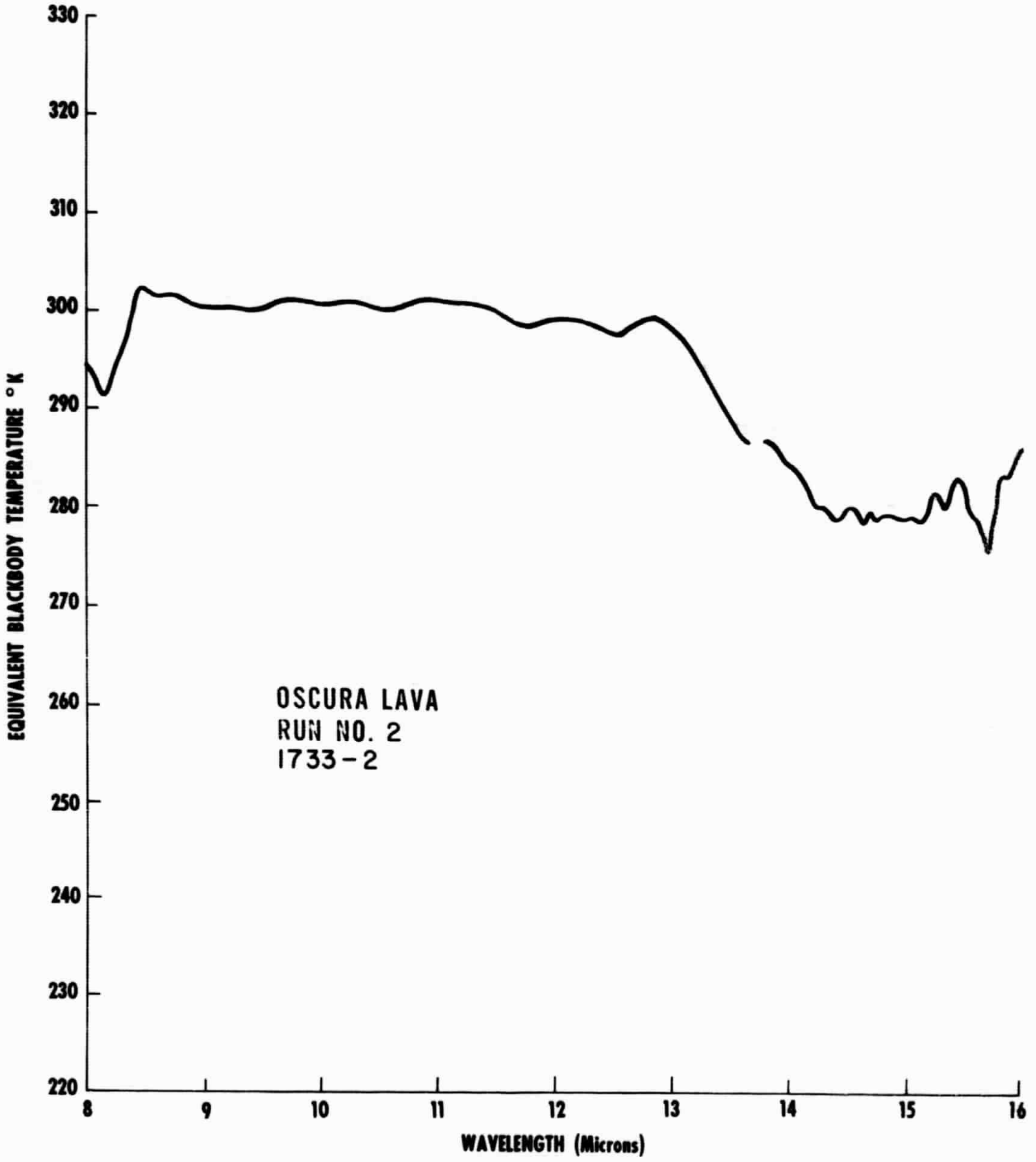


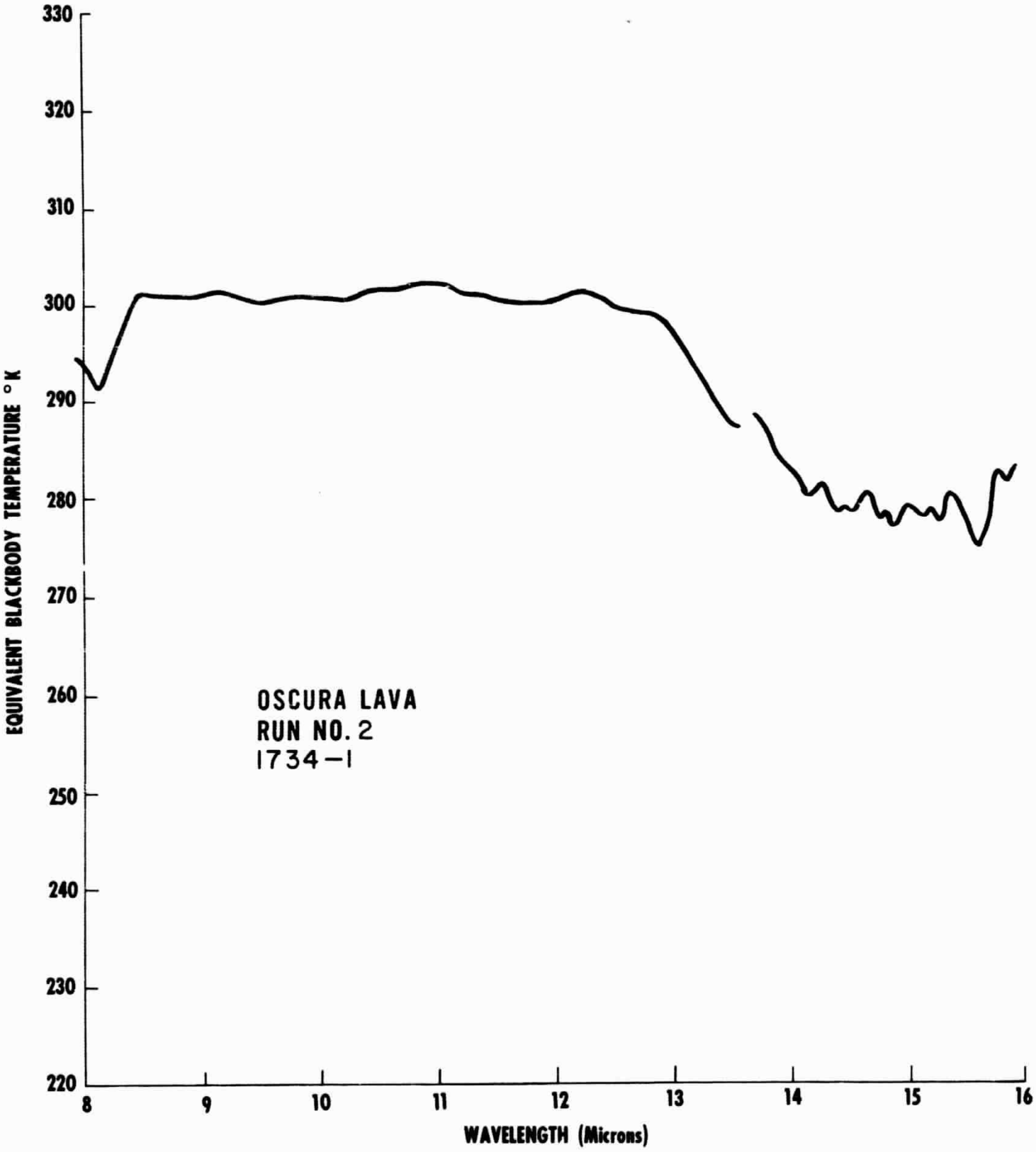
330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 2
1731-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

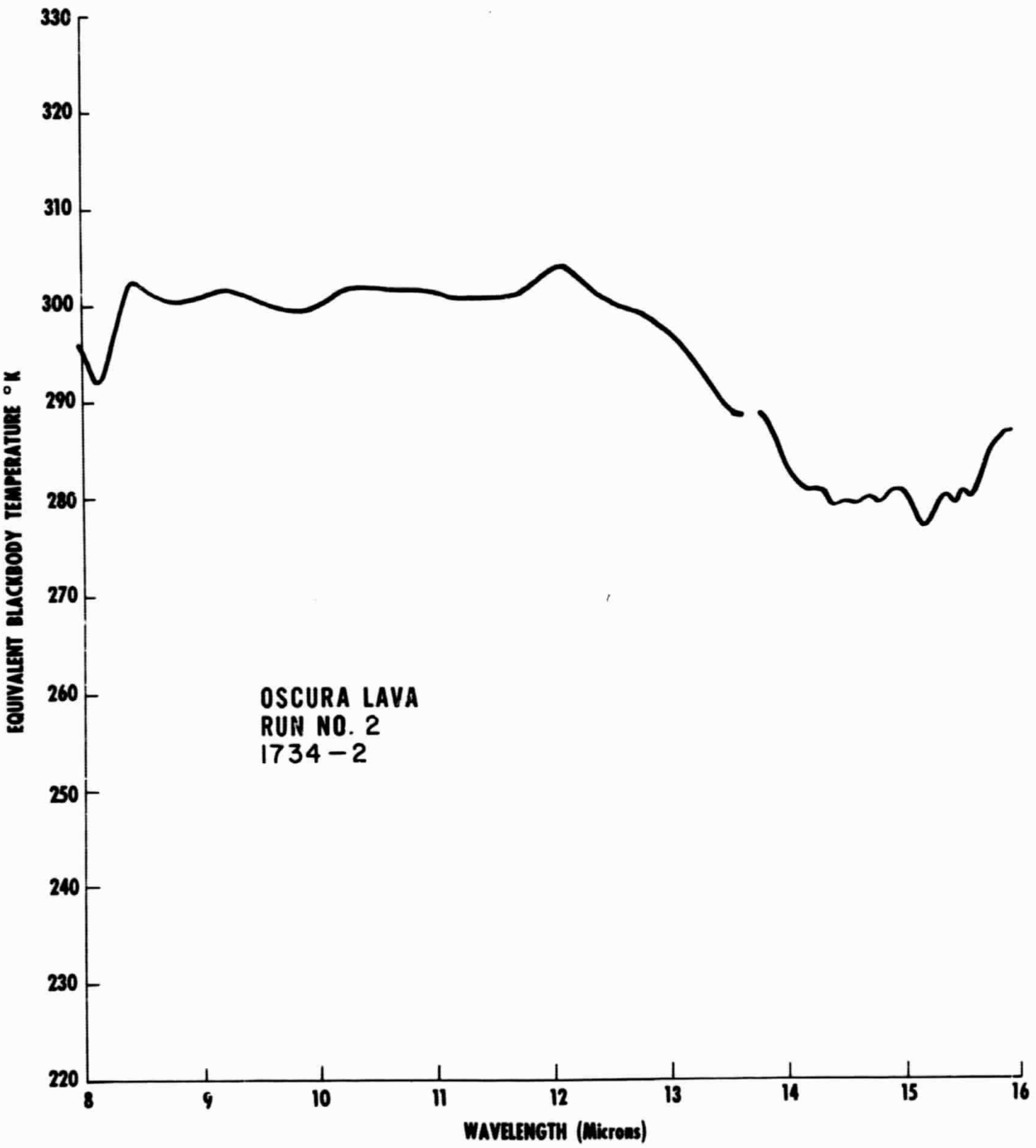


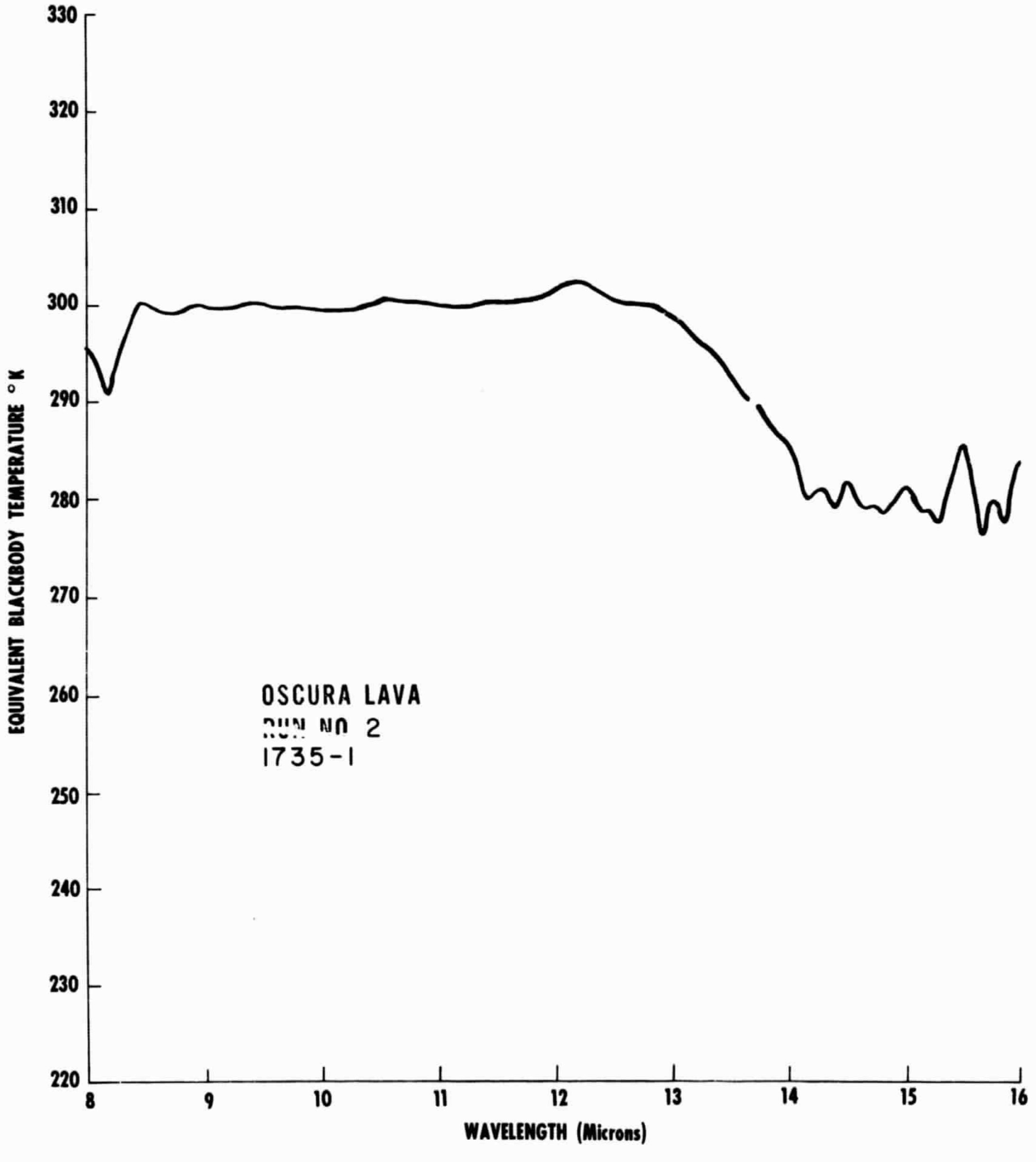
330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 2
1732-1

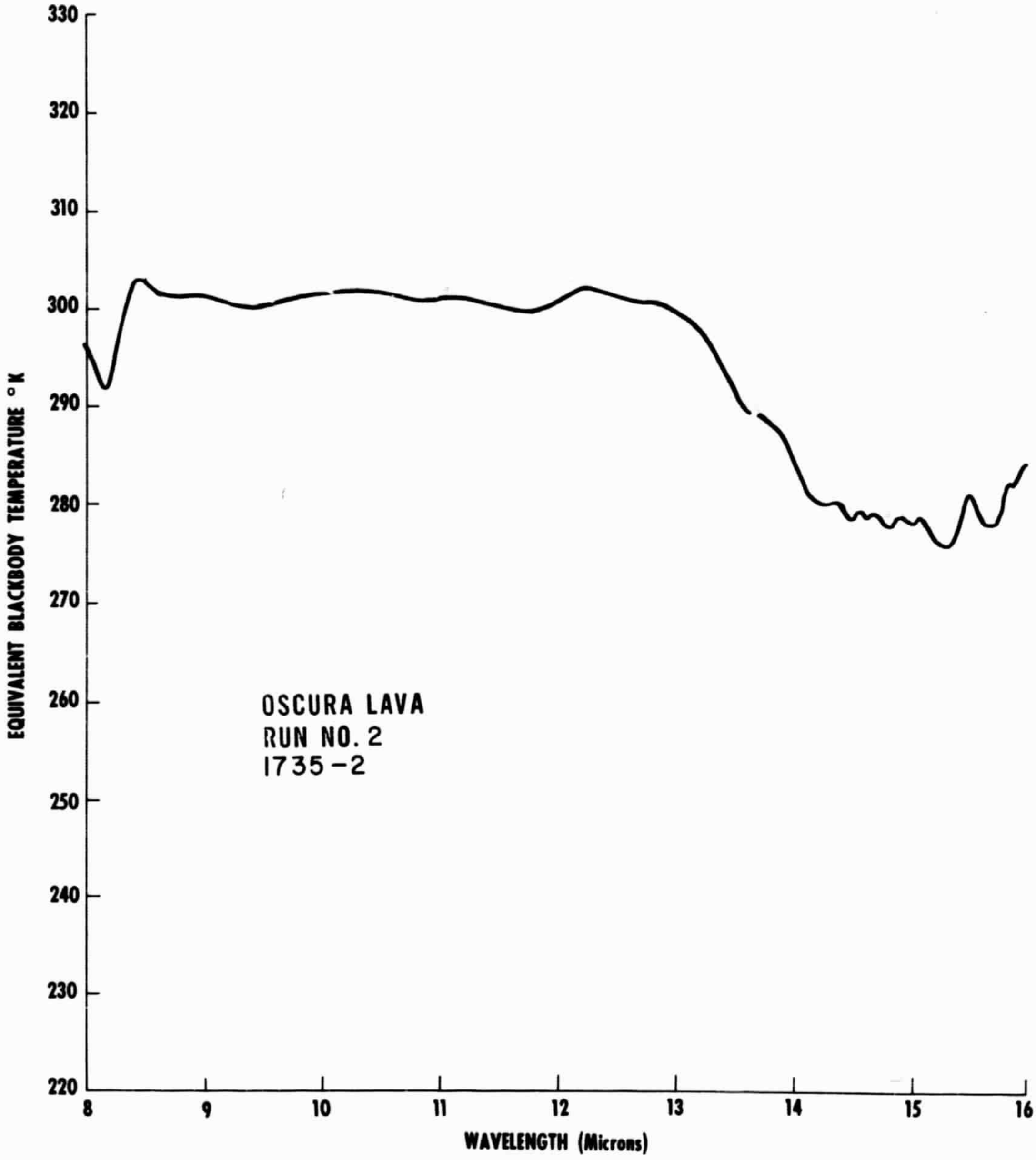

330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 2
1733 – 1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 2
1733-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 2
1734—1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
300
290
280
270
260
250
240
230
220
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 2
1734 – 2


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO 2
1735-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
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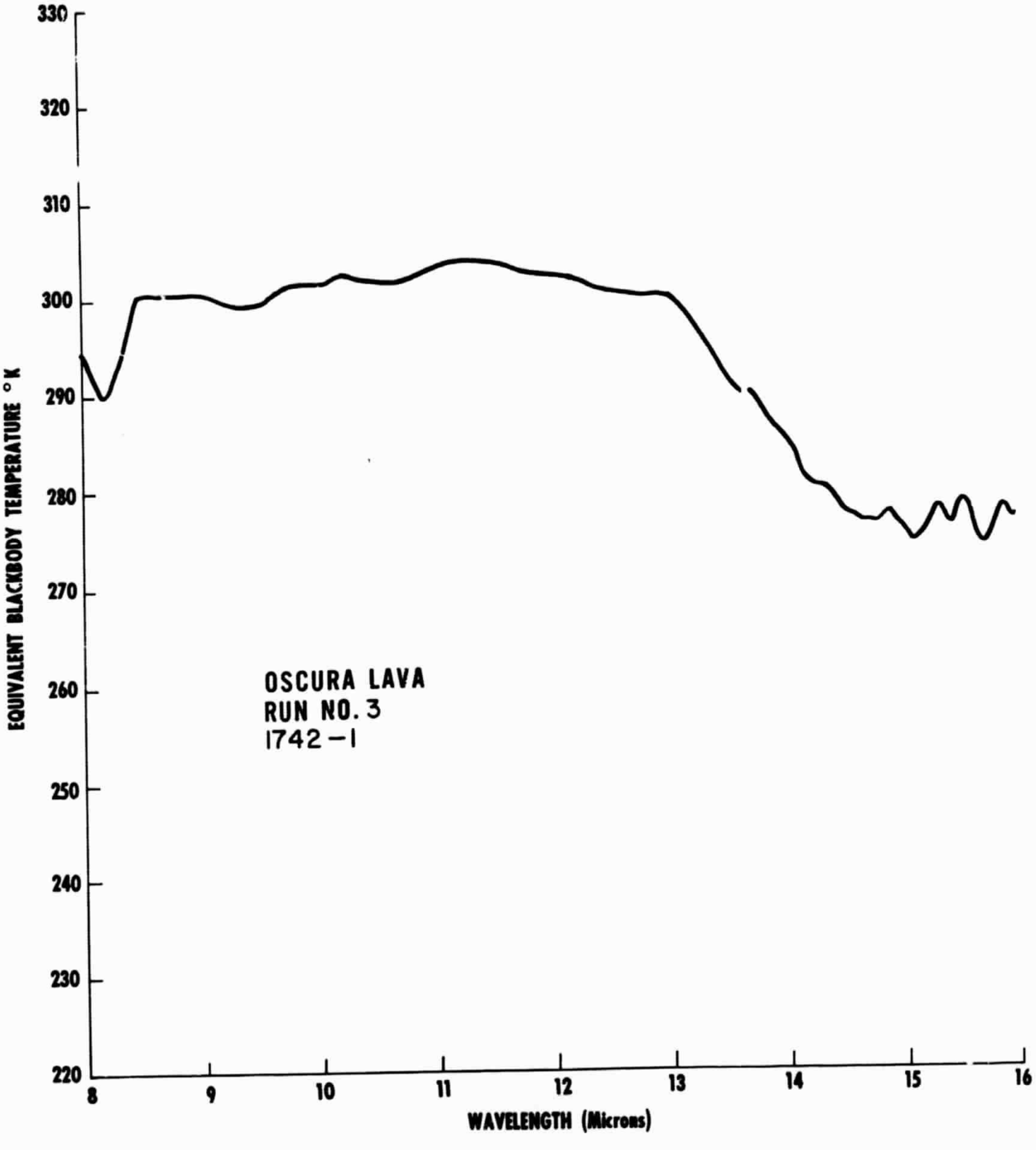
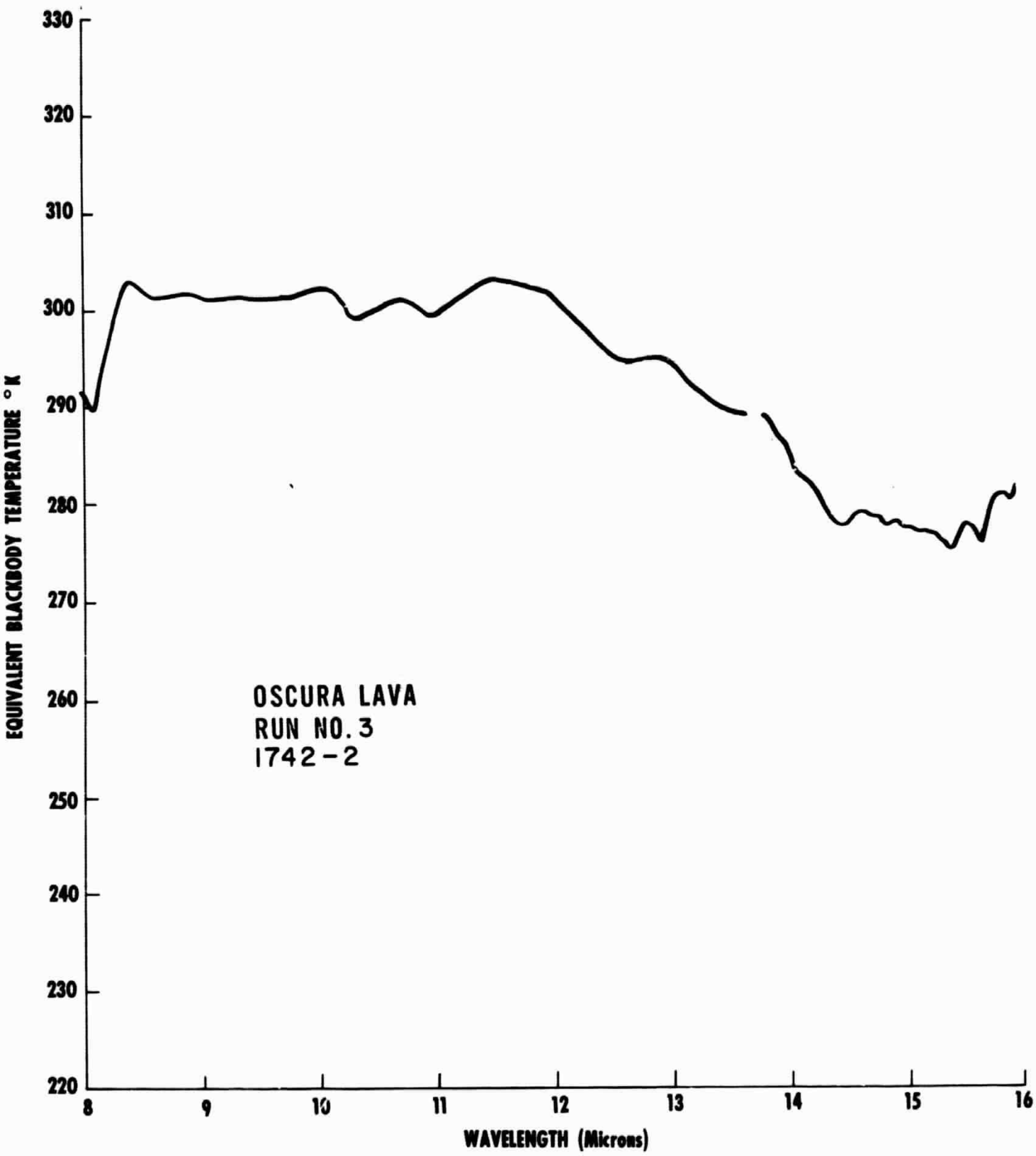
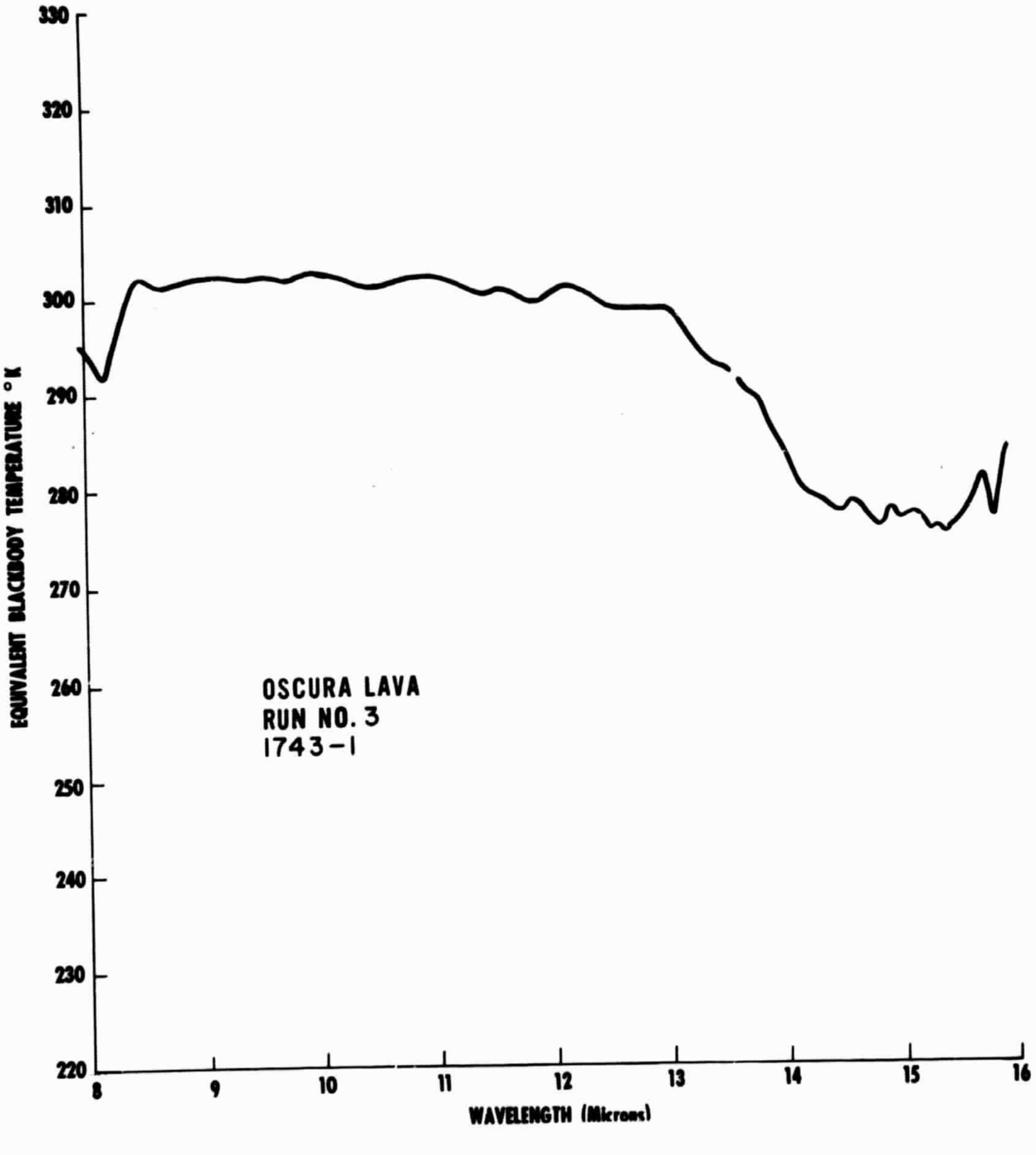
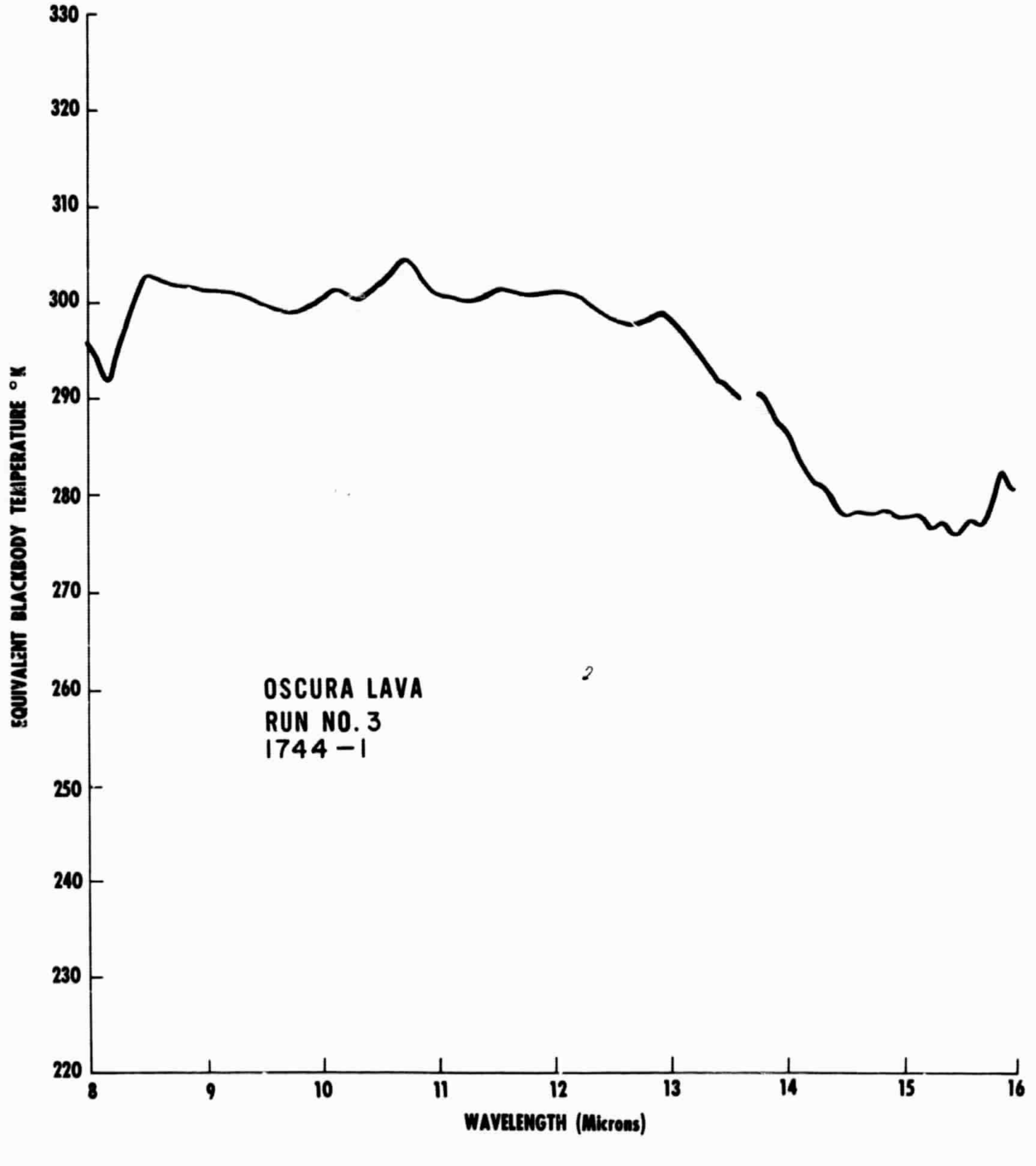
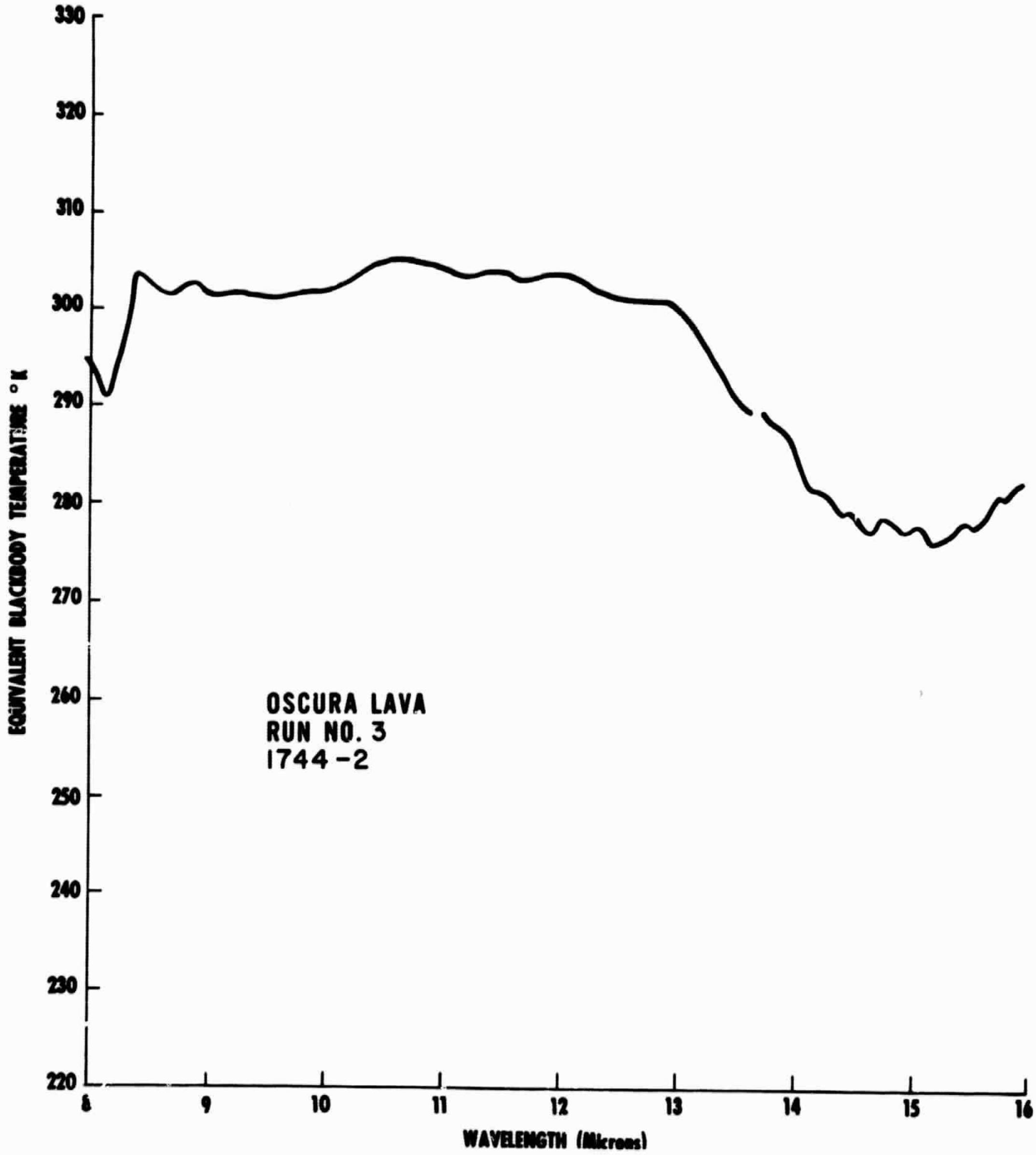
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 2
1735-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

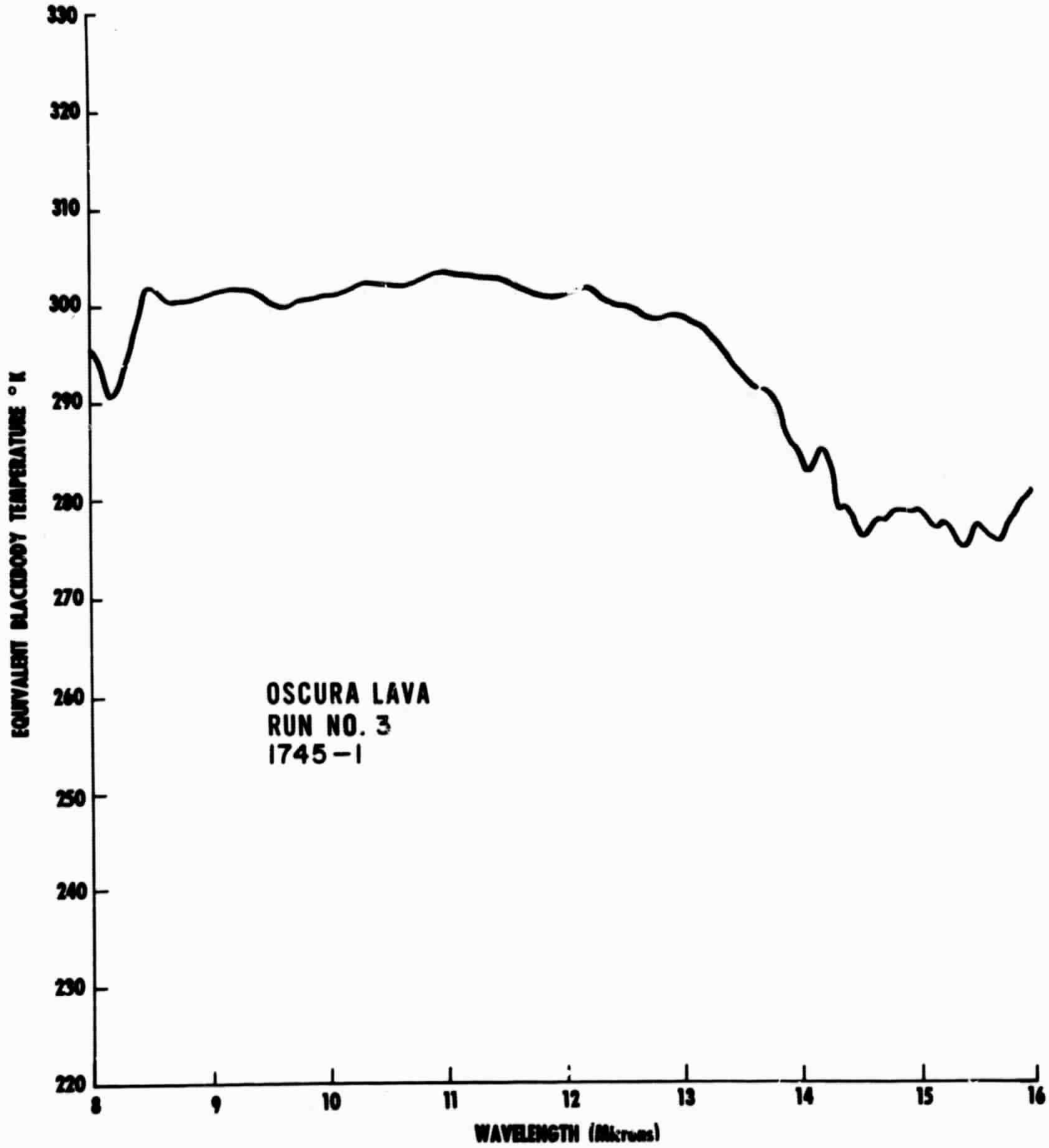

330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 3
1742-1

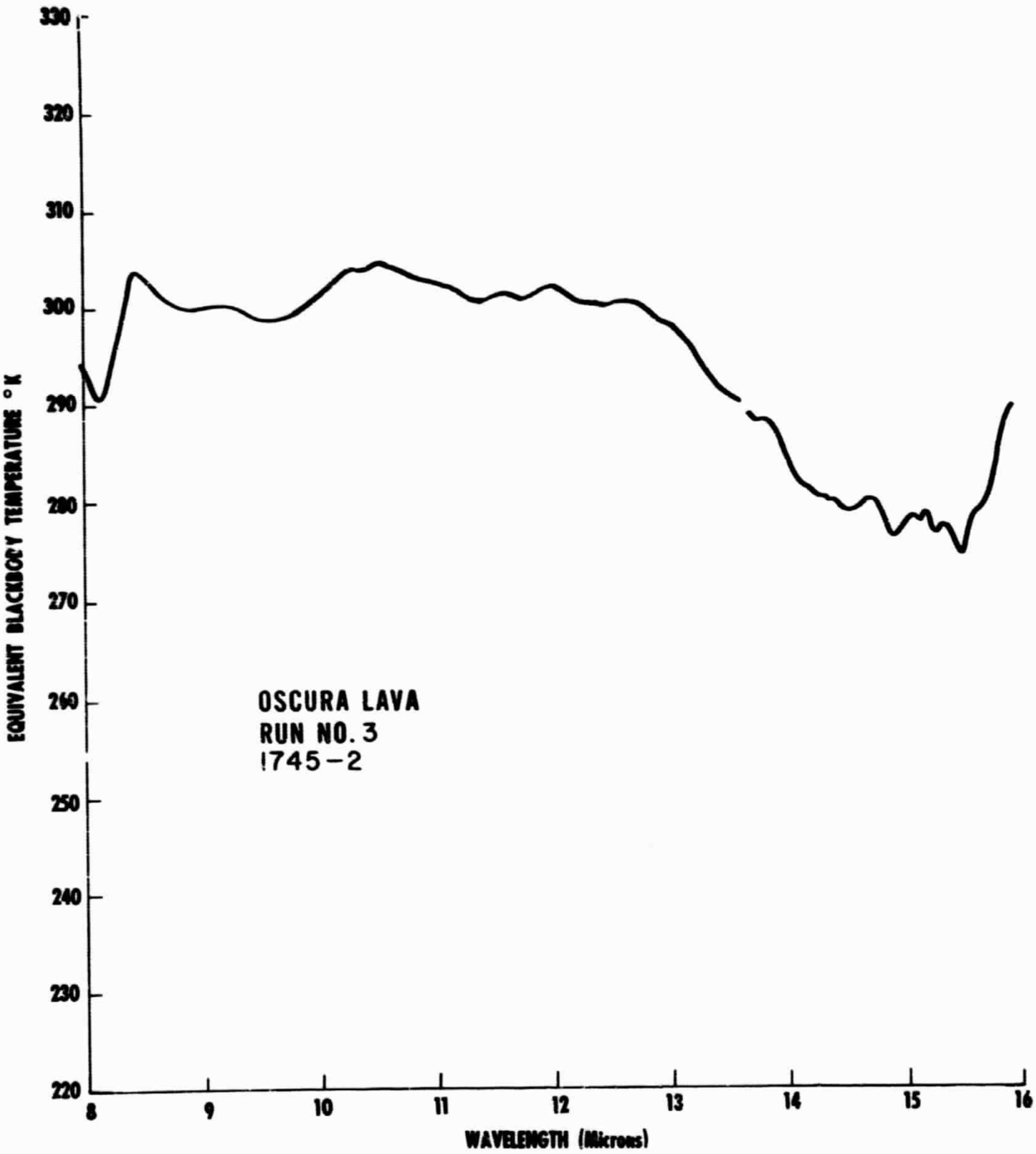

330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 3
1742-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


OSCURA LAVA
RUN NO. 3
1743-1
EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
300
290
280
270
260
250
240
230
220
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 3
1744 – 1


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 3
1744-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 3
1745-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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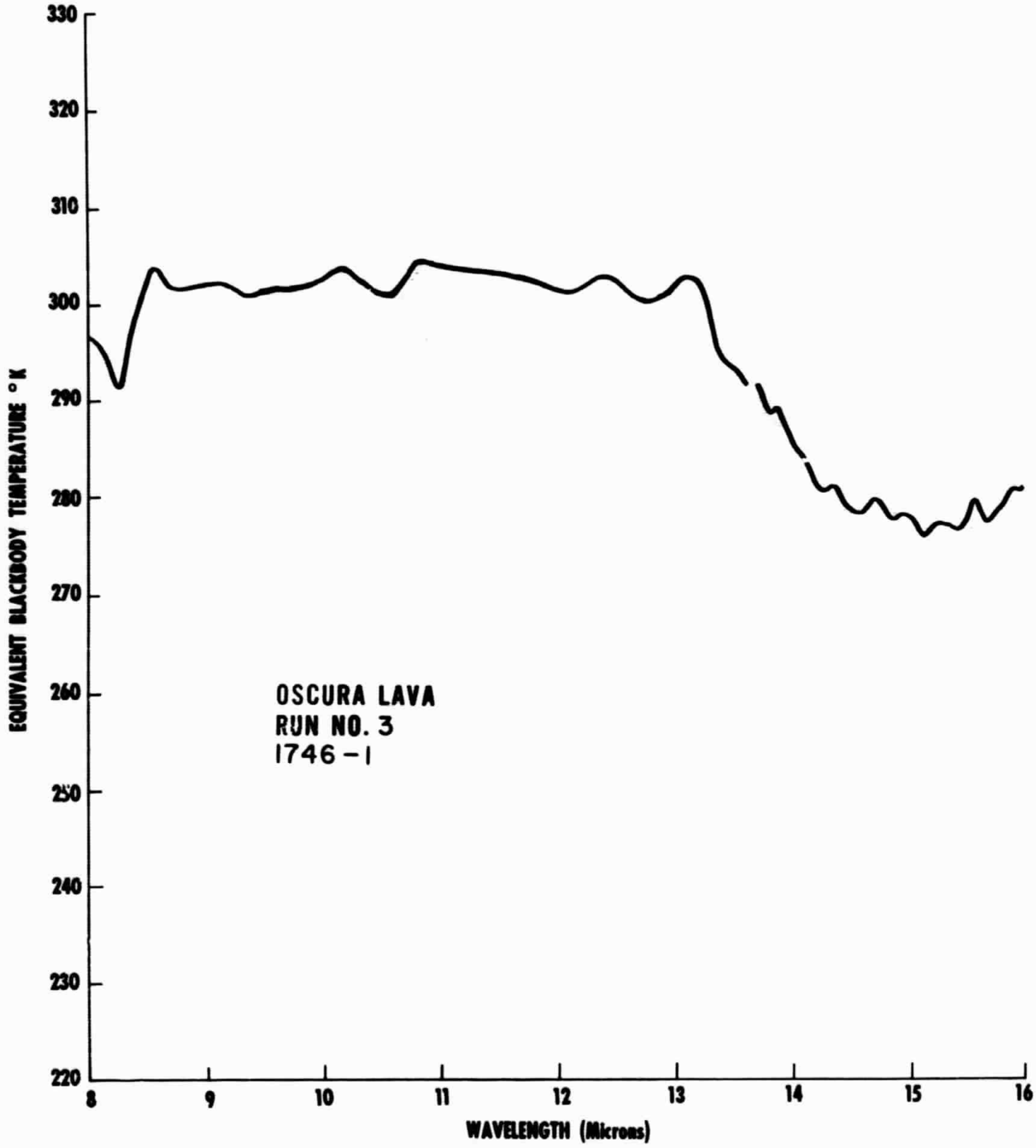
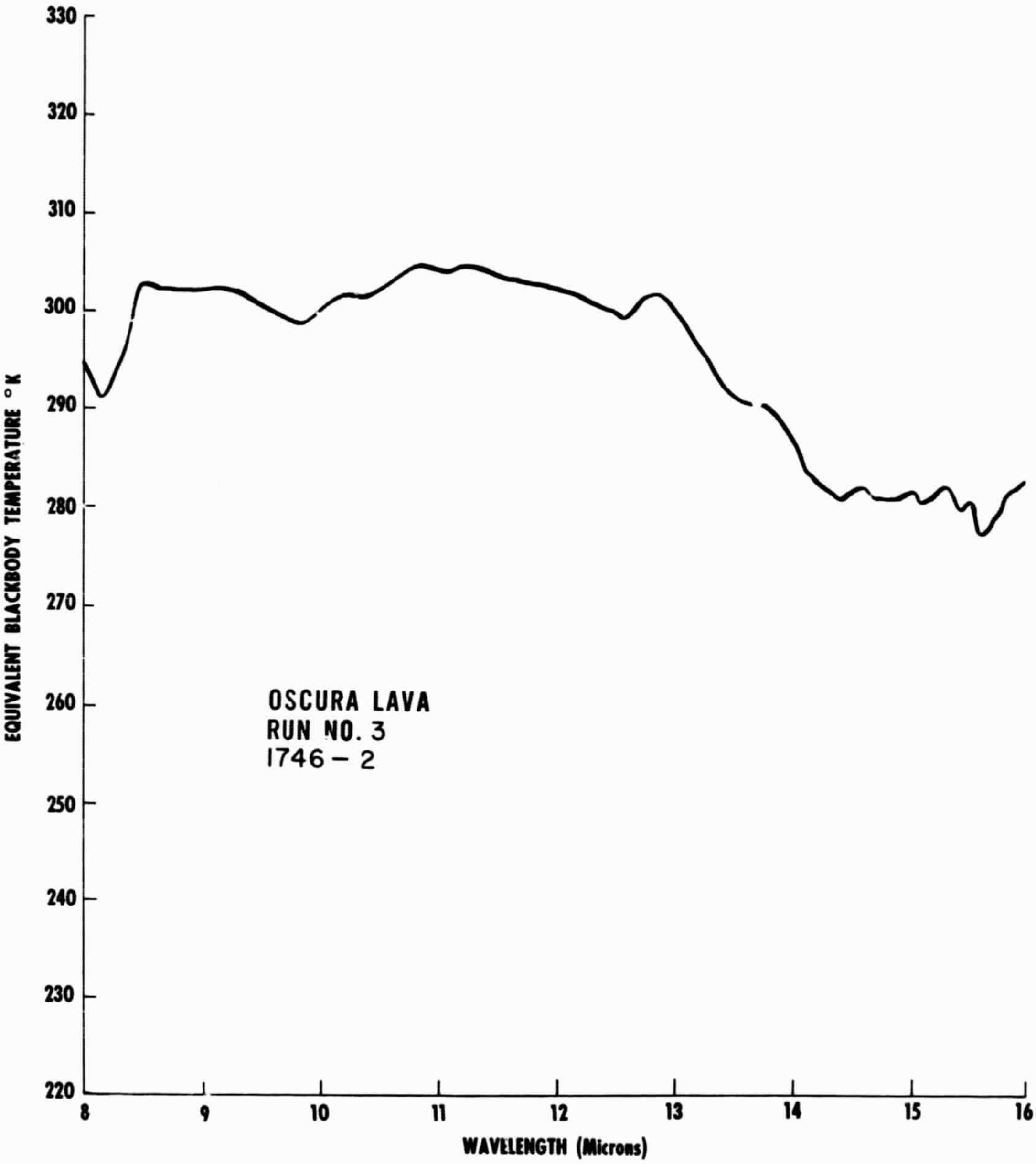
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 3
1745-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)



330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 3
1746 - 1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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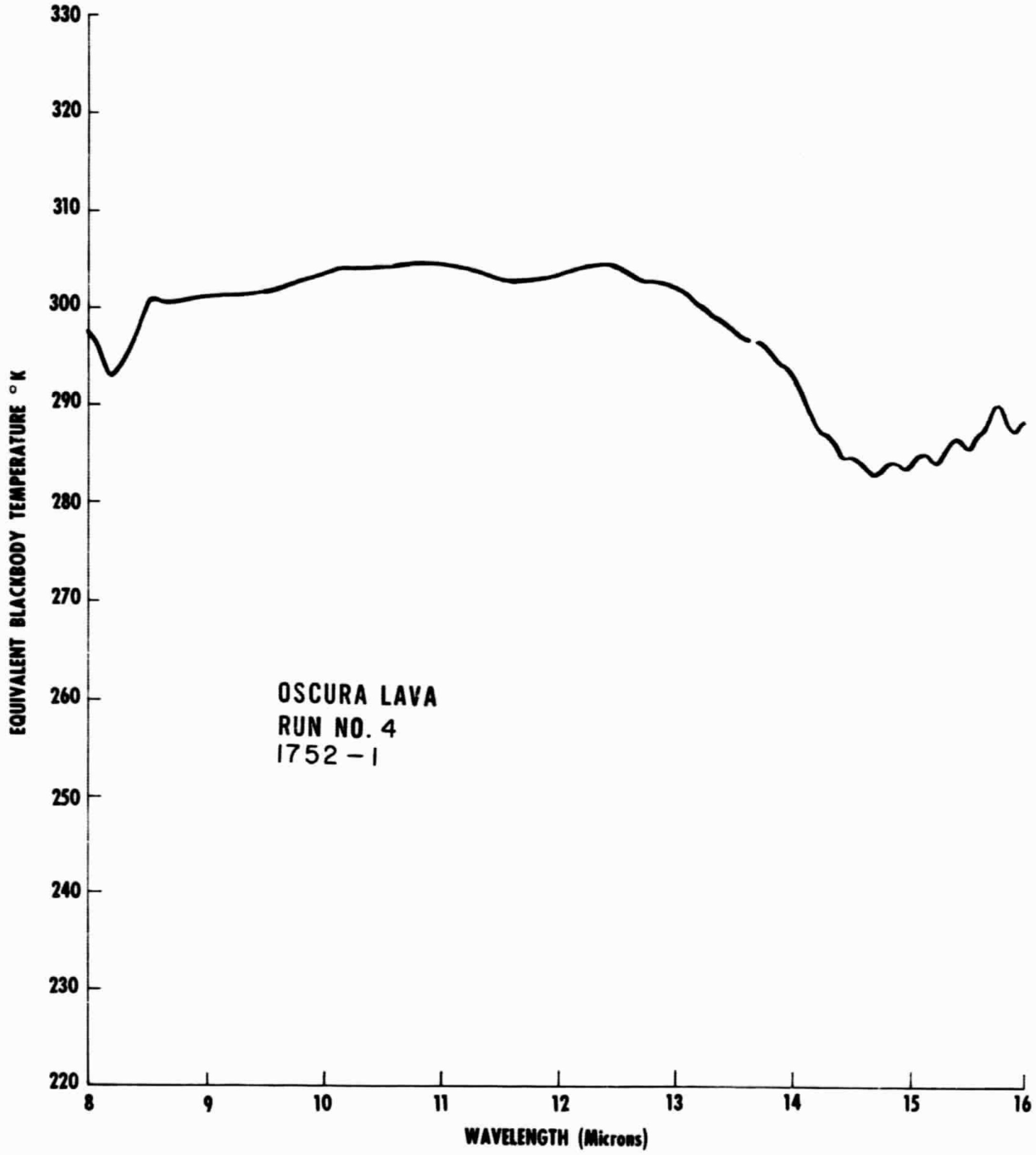
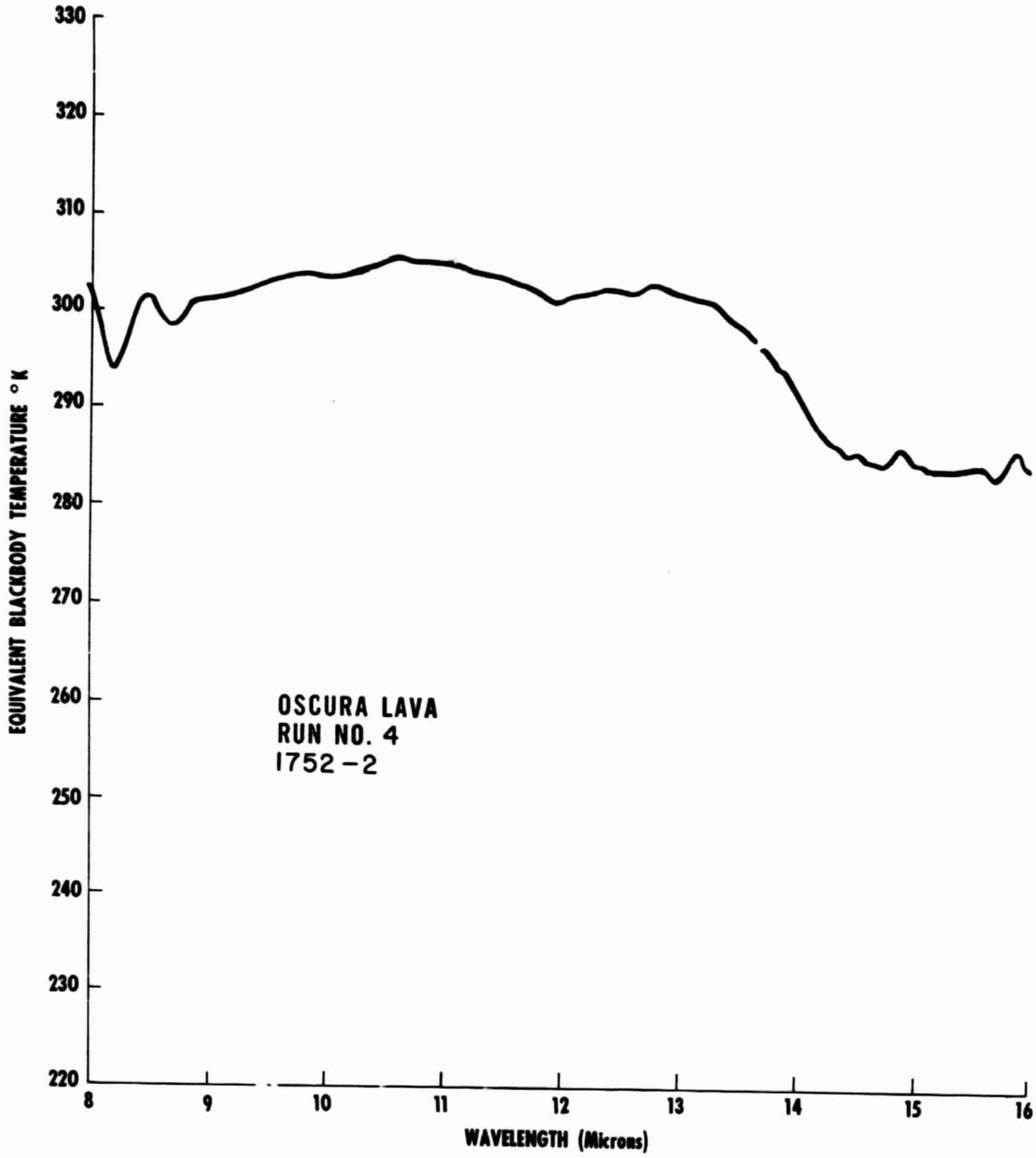
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 3
1746 – 2


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 4
1752 - 1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
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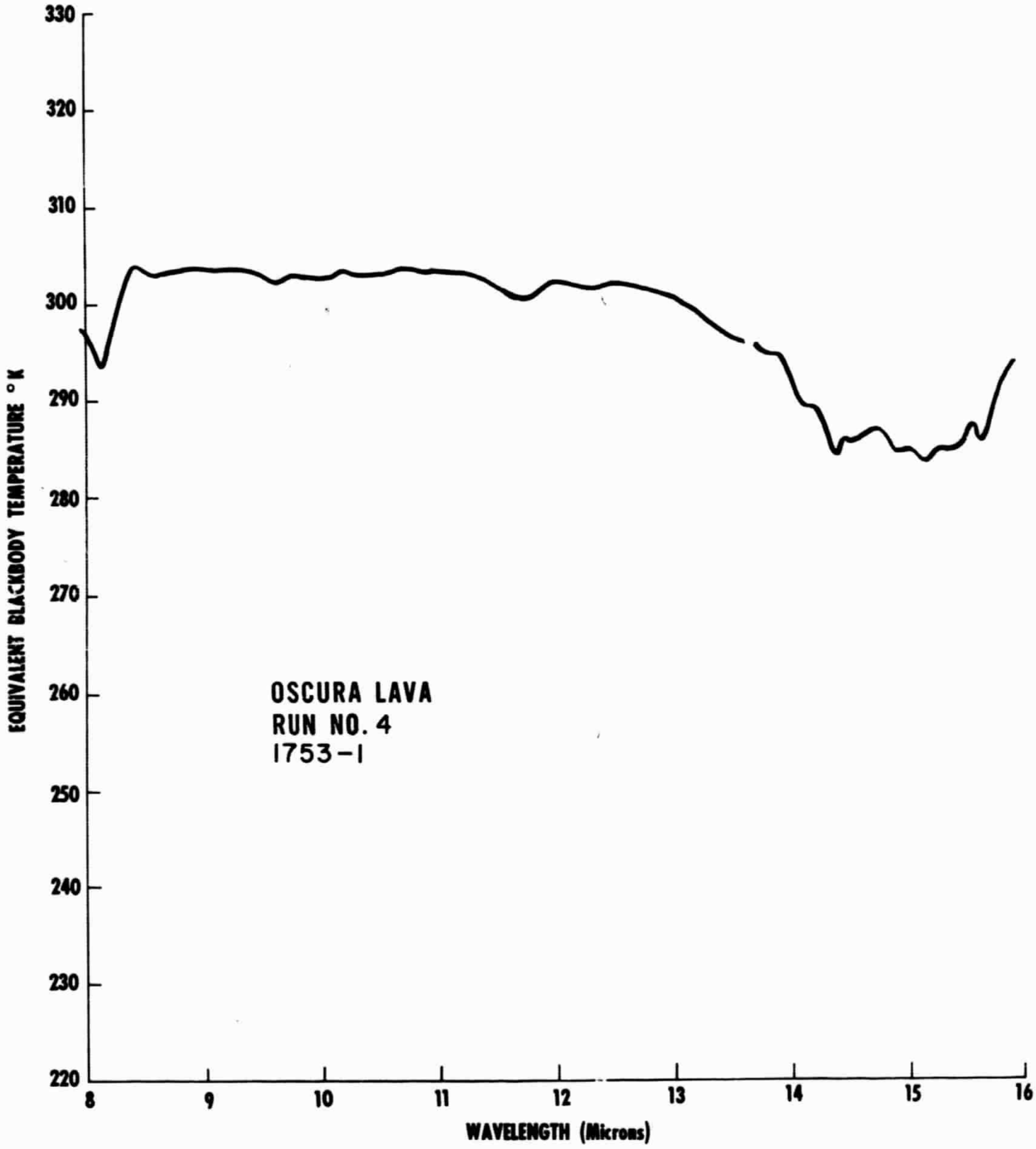
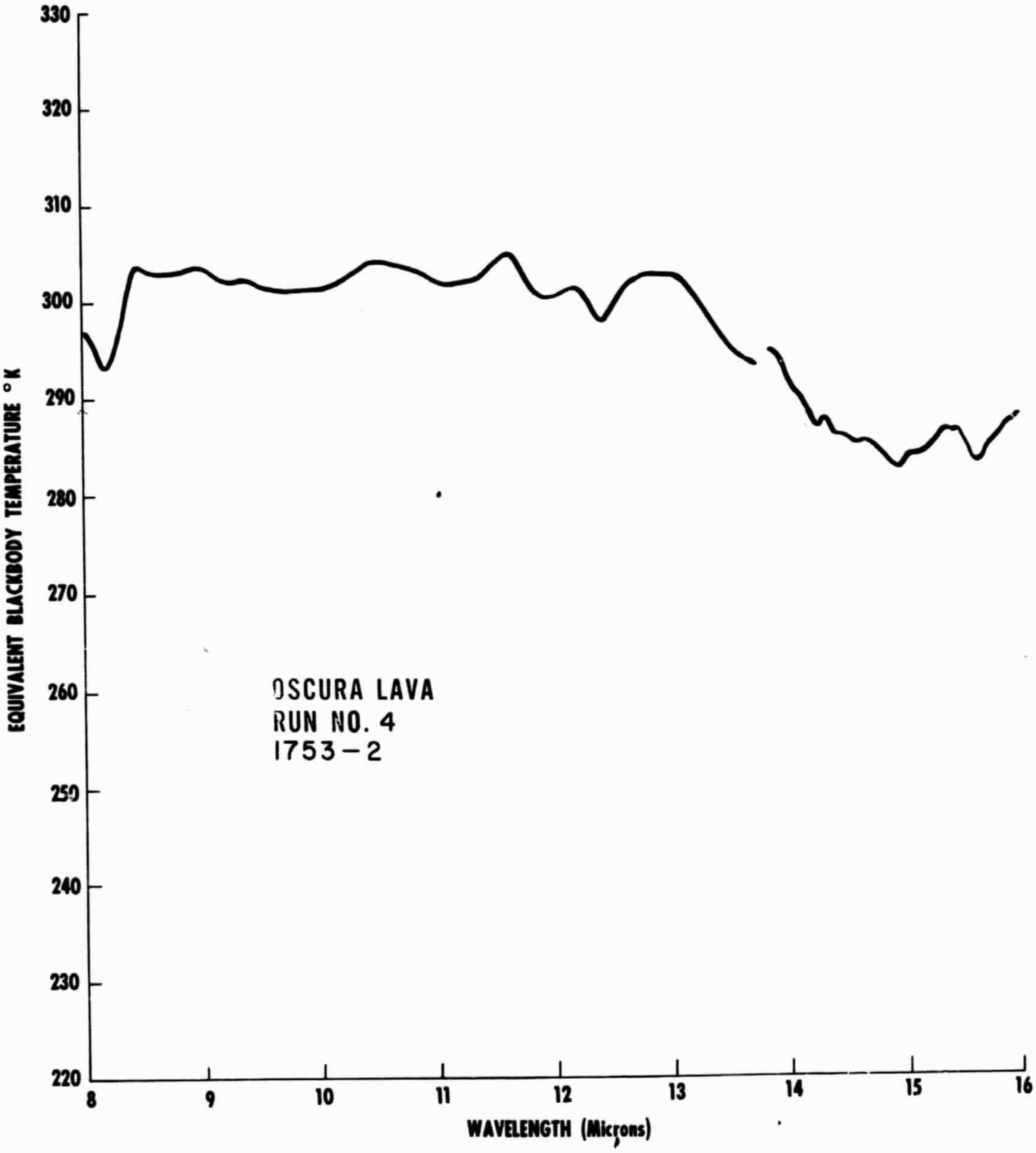
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 4
1752-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 4
1753-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)



330
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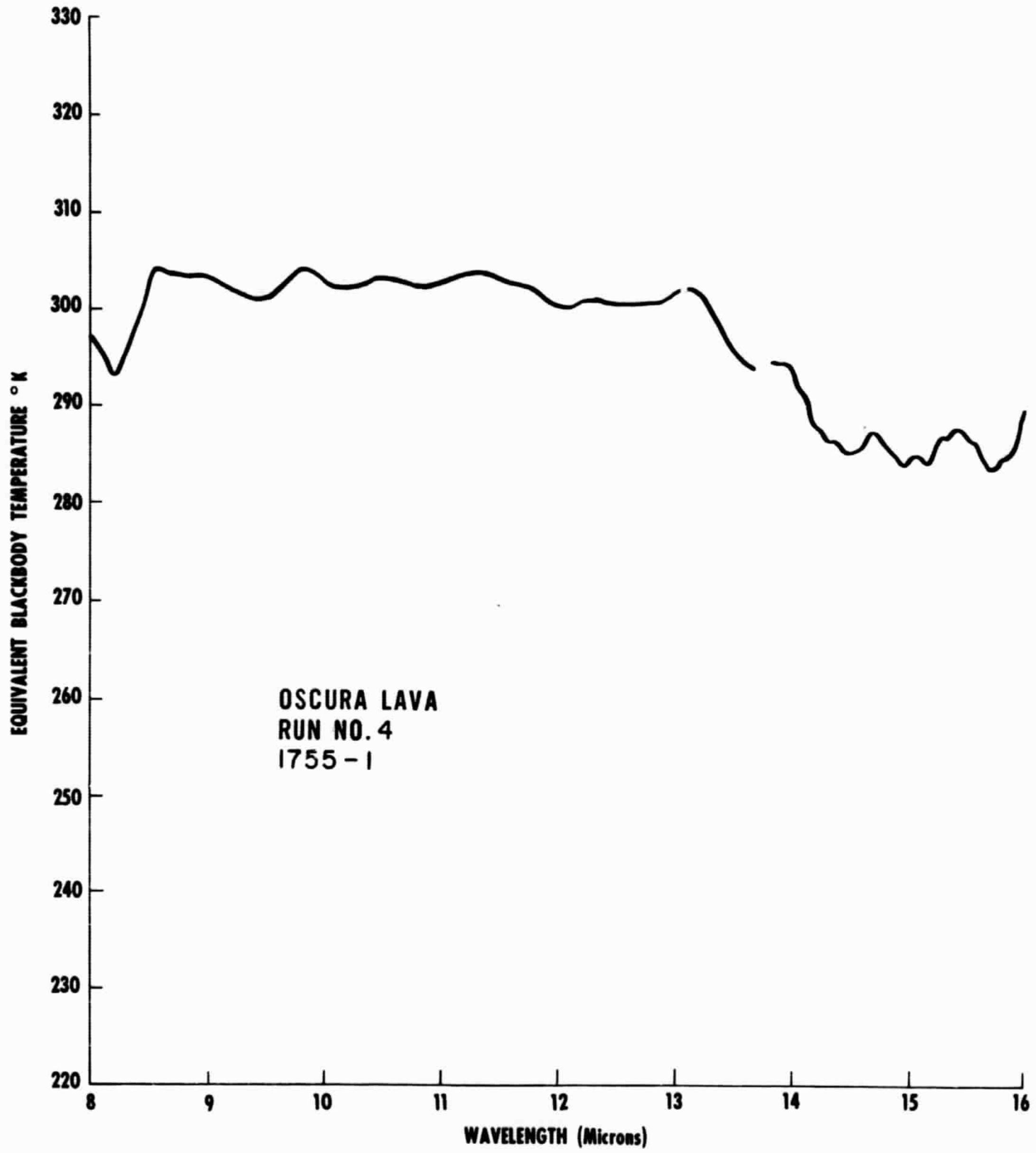
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 4
1753-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)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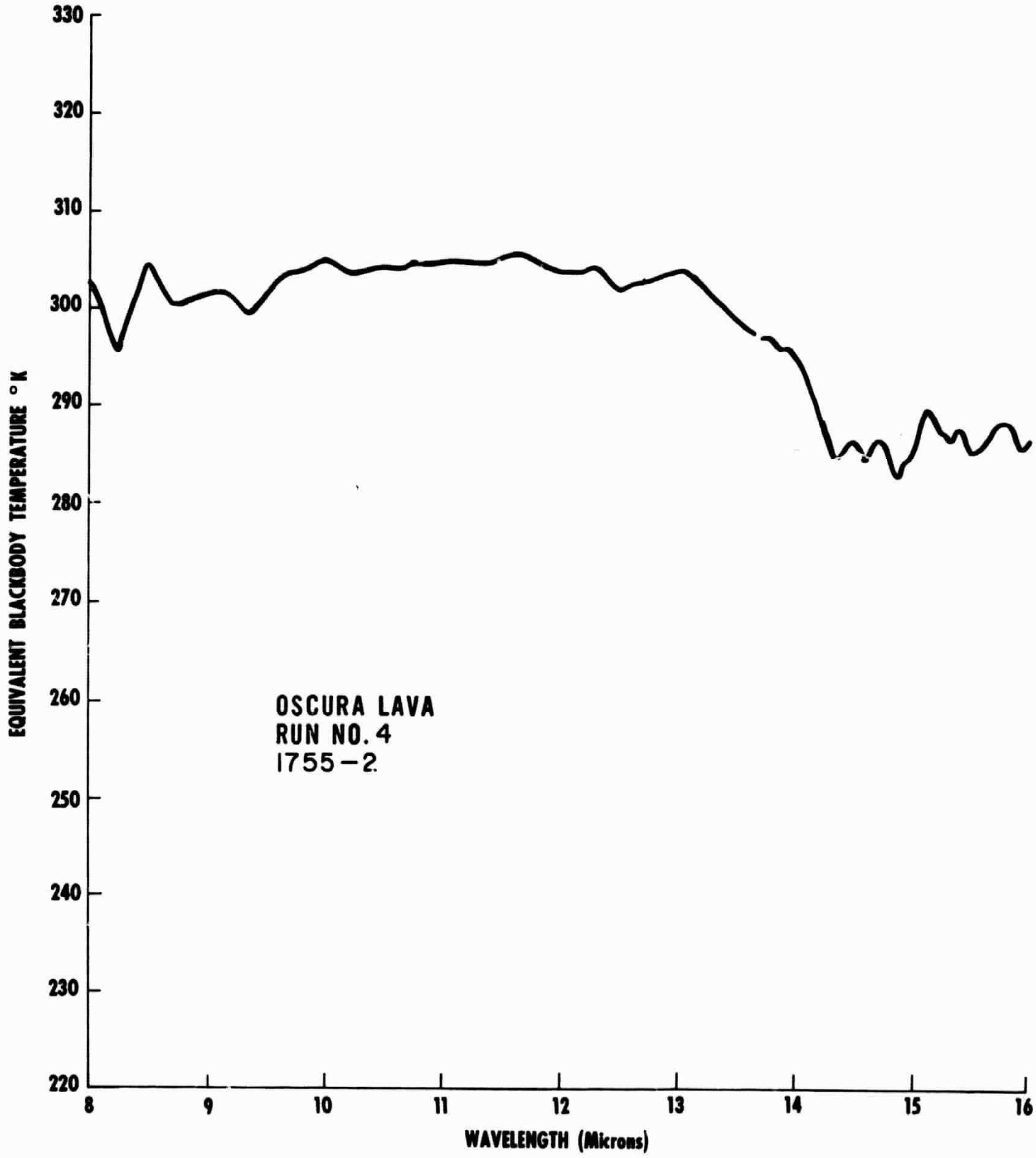
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 4
1755 - 1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
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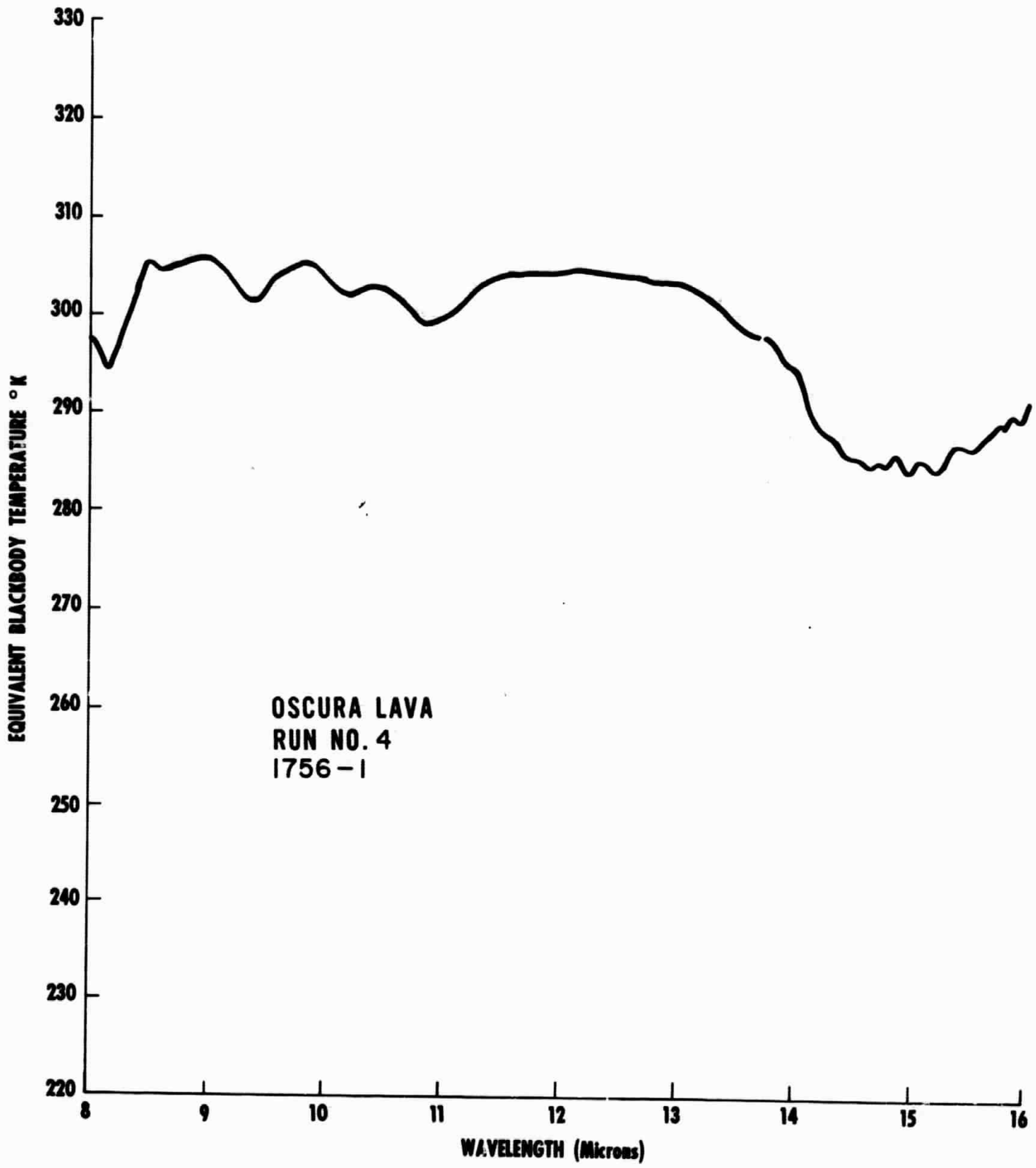
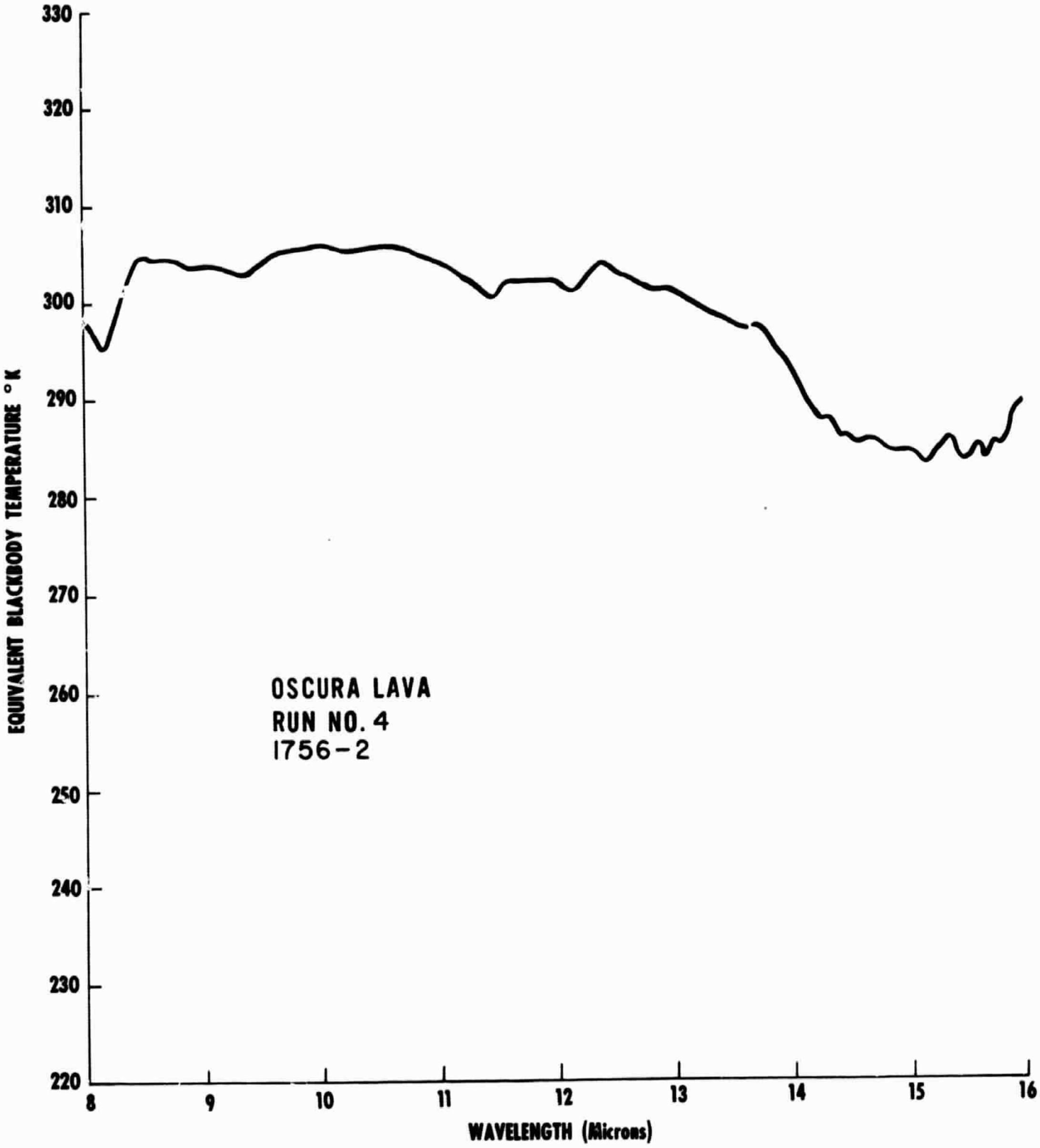
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 4
1755-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
300
290
280
270
260
250
240
230
220
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 4
1756-1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320
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280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 4
1756-2
8
9
10
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14
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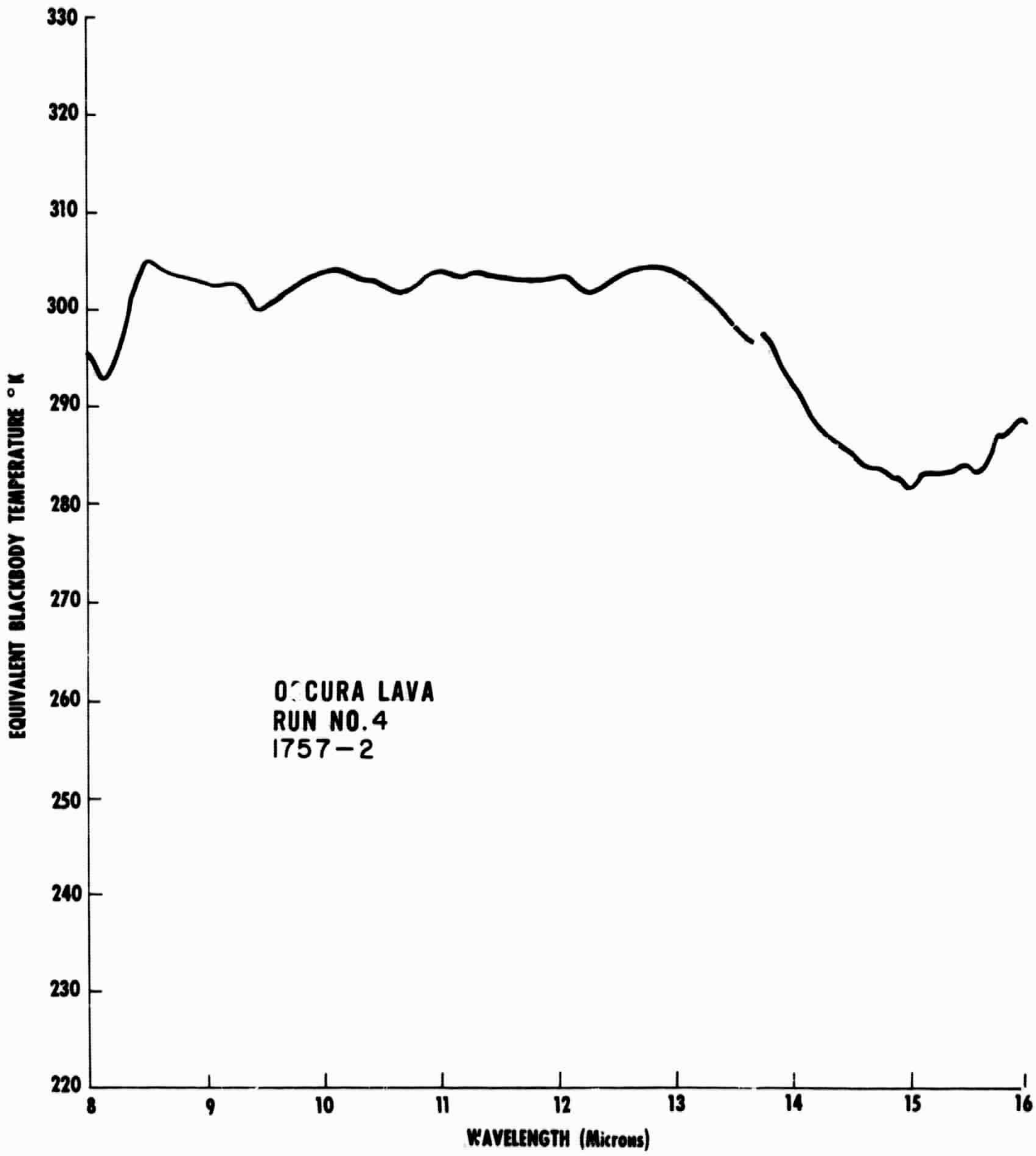
16
WAVELENGTH (Microns)



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260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
8
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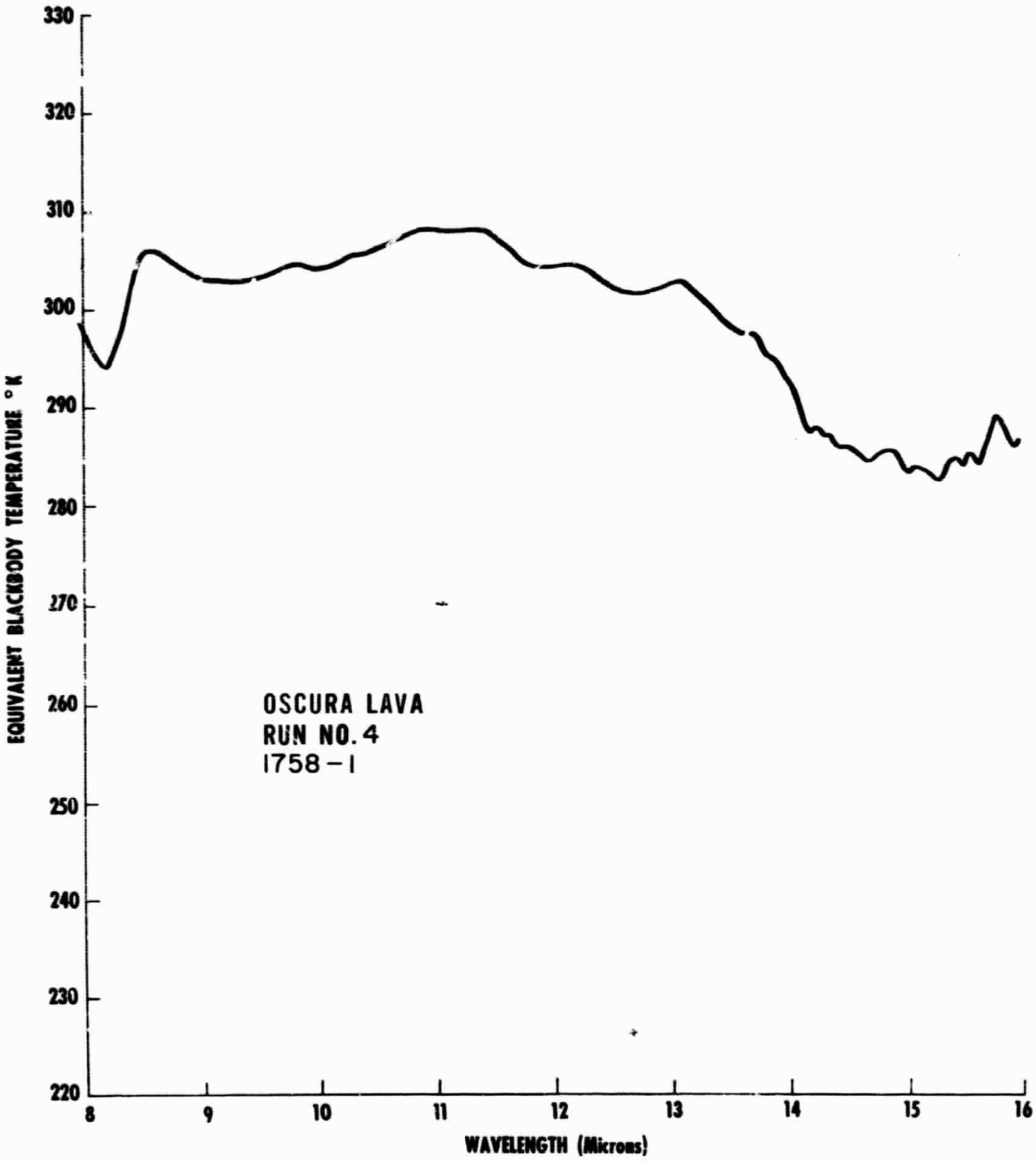
16
WAVELENGTH (Microns)
O:CURA LAVA
RUN NO.4
1757-2



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250
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230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
8
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14
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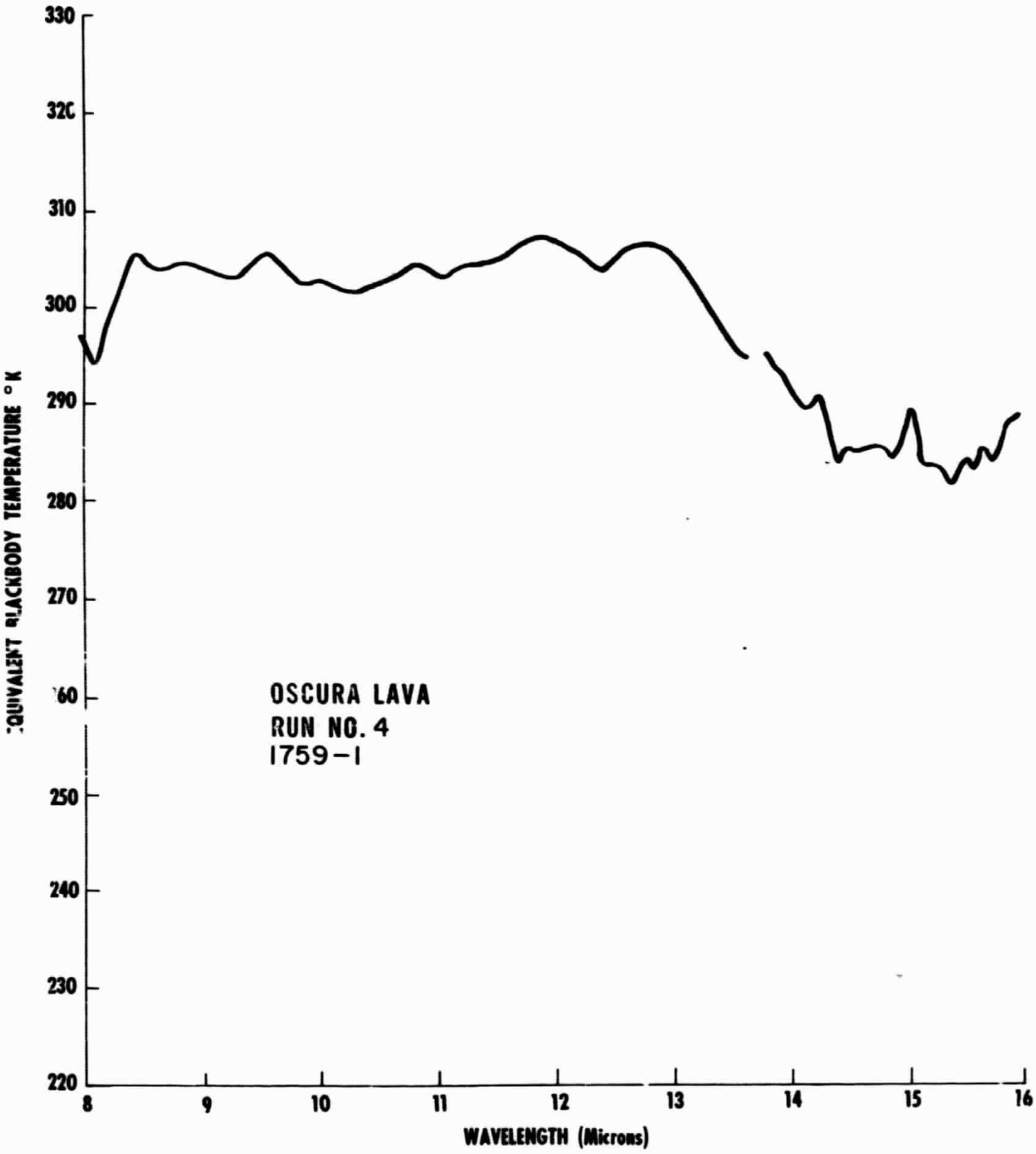
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 4
1758 - 1



EQUIVALENT BLACKBODY TEMPERATURE °K
330
320
310
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280
270
260
250
240
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220
8
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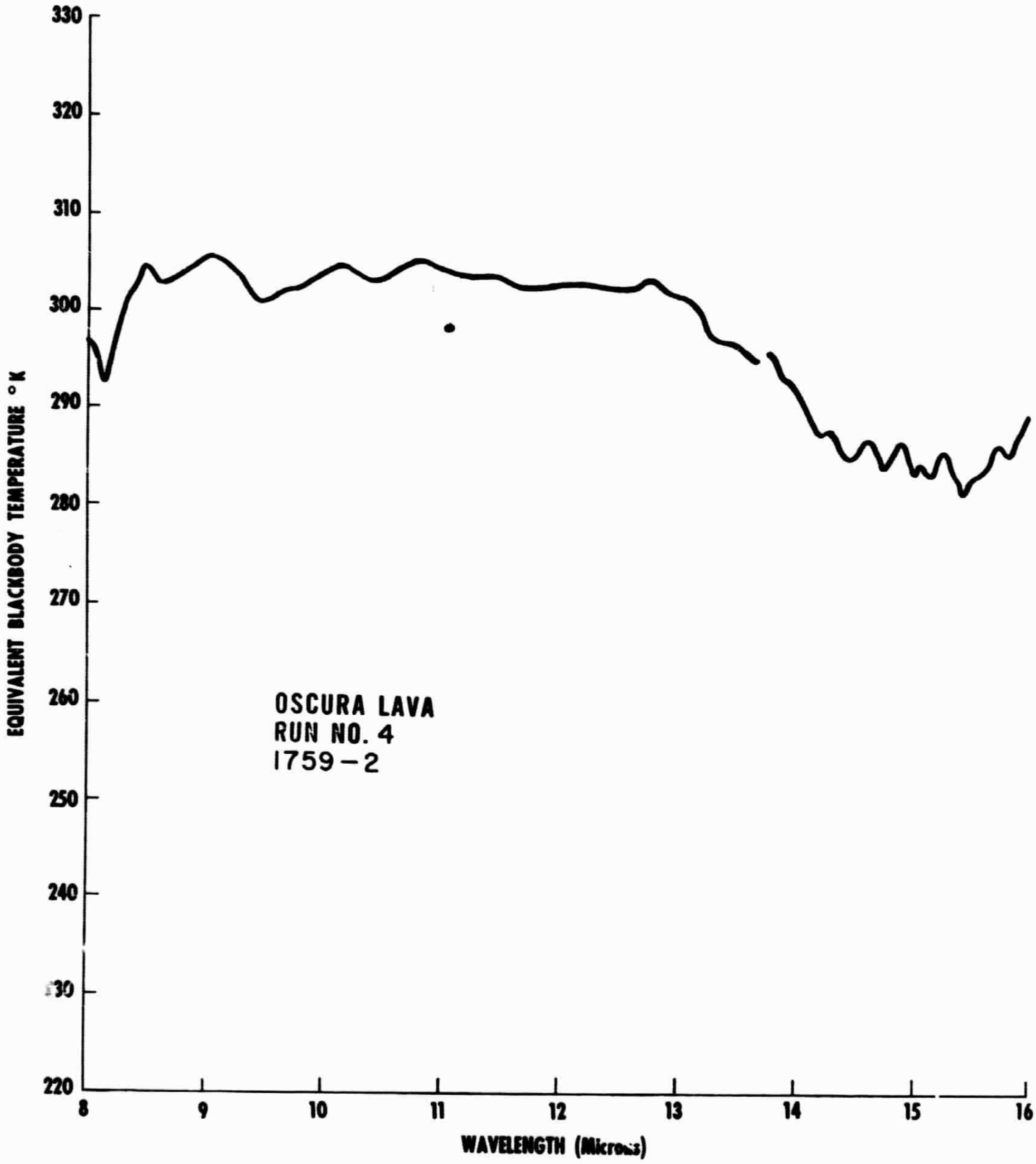
16
WAVELENGTH (Microns)
OSCURA LAVA
RUN NO. 4
1759-1



330
320
310
300
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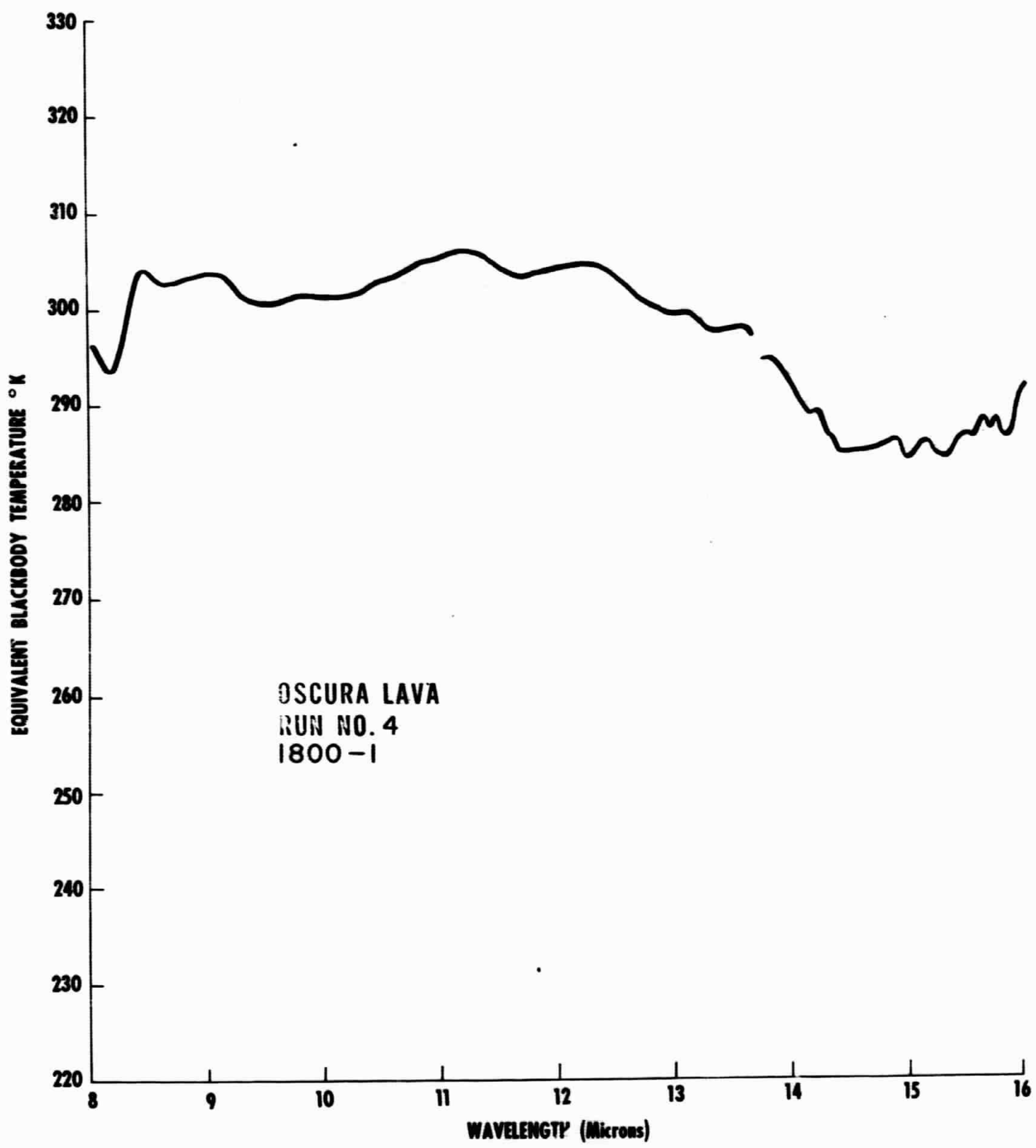
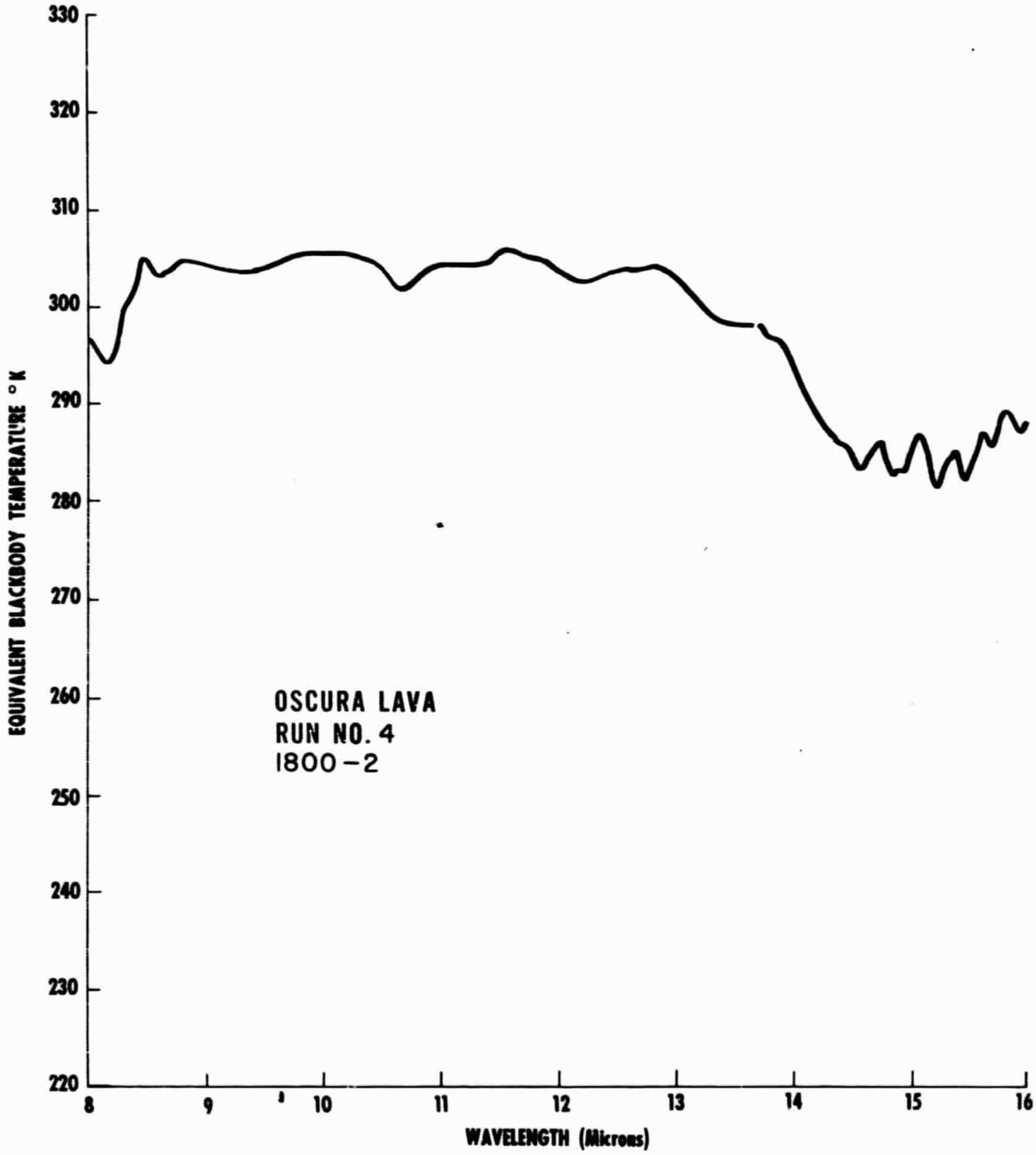
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 4
1759-2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE ° K
OSCURA LAVA
RUN NO. 4
1800-1
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)


330
320
310
300
290
280
270
260
250
240
230
220
EQUIVALENT BLACKBODY TEMPERATURE °K
OSCURA LAVA
RUN NO. 4
1800 – 2
8
9
10
11
12
13
14
15
16
WAVELENGTH (Microns)

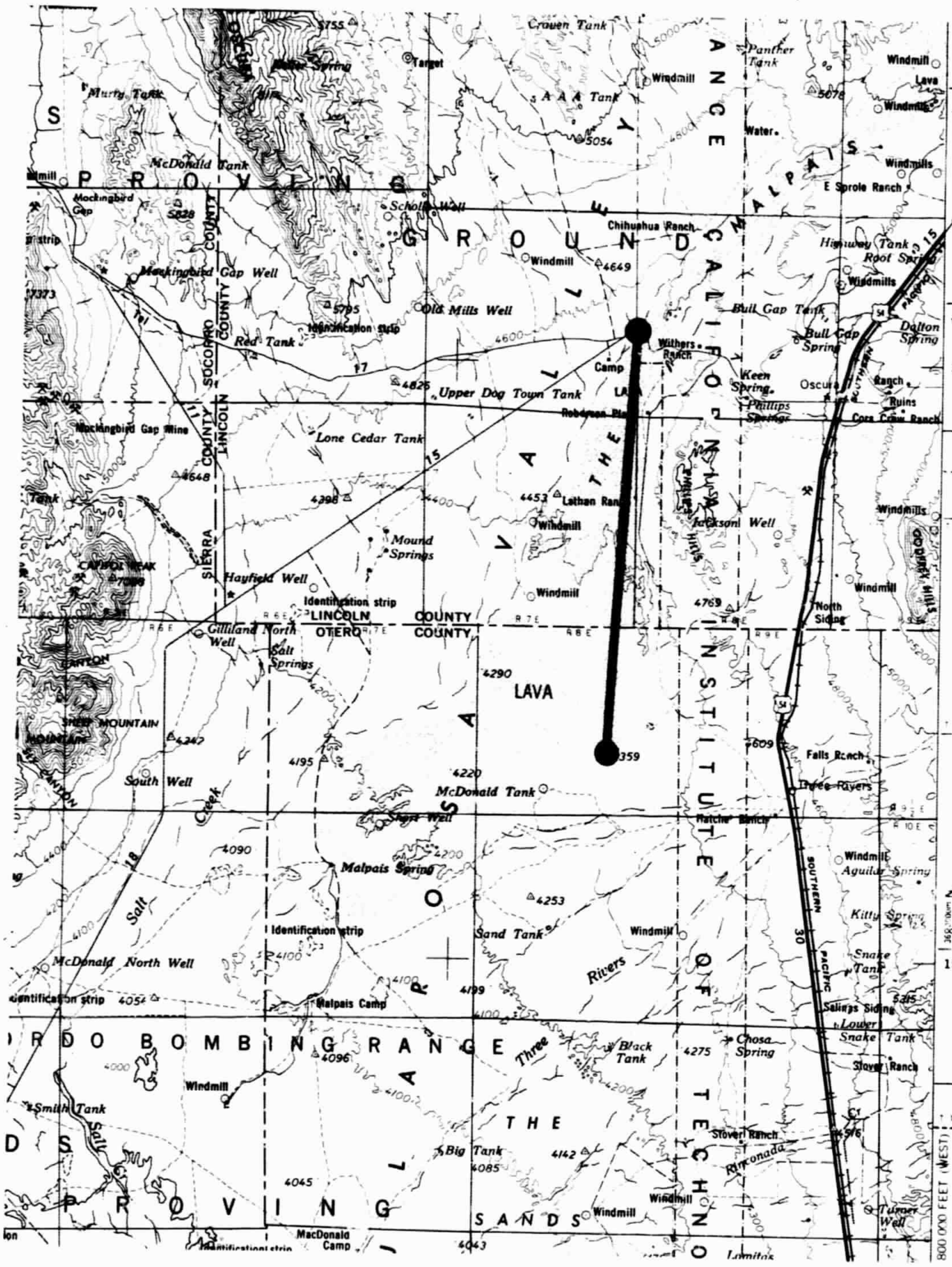


Figure 6